AN

HISTORICAL ACCOUNT

OF THE

ORIGIN AND PROGRESS

OF

ASTRONOMY.

WITH PLATES ILLUSTRATING, CHIEFLY, THE ANCIENT SYSTEMS

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"Credo Deos immortales sparsisse animos in corpora humana, ut essent, qui terras tuerentur, quique, cœlestium ordinem contemplantes, imitarentur eum vitæ modo atque constantiâ."

CICERO, DE SENECTUTE, CAP. XXI.

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PREFACE.

THE object of the Work now submitted to the public is to indicate the probable origin, and to trace the progress, of astronomical science. Setting out with a view of the heavens, the sentiments which that view may be supposed to excite are described, and the purposes to which the most obvious phenomena might be made subservient are stated. In the next place, the manner in which the ancients endeavoured to explain the constitution of the universe, and account for the movements observed in the heavenly bodies, is shewn. The successive changes made in the celestial mechanism, in proportion as the phenomena were more attentively considered, are then detailed, and the Work terminates with an outline of the system founded on the received hypothesis of gravitation.

From the relations transmitted by some of the ancient writers, and from those delivered by modern navigators, we find that men, in the lowest grade of civilisation, have always entertained nearly the same ideas concerning the forms of the earth and heavens, and that they have drawn those ideas immediately from the information afforded by the senses alone. It is certain, also, that from the time at which the proper movements of the sun, moon and planets were first detected, till the hypothesis of the earth's motion was recognised, in the days of Copernicus and Kepler, the opinion that each of those celestial bodies was attached to the surface of a revolving sphere was universally held. But the faint and dubious hints to be found in the existing works of the ancients being insufficient to guide us to a knowledge of the manner in which the periodical revolutions of the planets were originally observed, this is, necessarily, in part,

supplied by conjecture. In the following pages, however, care has been taken to suppose, in the discoverer, no previous information, except such as might be furnished by those phenomena which are manifest to an unassisted eye, and which could not have escaped an attentive observer, and it will, probably, be admitted that the notions imagined to arise on contemplating the moving bodies in the firmament are precisely those which would occur to the mind of an intelligent spectator, if placed in such circumstances

It has been attempted, in the present Work, to connect the history with the first elements of astronomy, in order that they who seek to obtain a knowledge of the science may derive assistance at the commencement of their enquiries, when any difficulty which the student may happen to encounter is most likely to deter him from the pursuit, and when, also, to keep alive his interest in the subject, there is need of some such allurement as may be found in a relation of the steps accomplished by the celebrated men of past ages Nor can it be doubted that the generous desire of participating in the renown acquired by the ancient masters in astronomy must, to those who have arrived at its principles by thus tracing the succession of discoveries, present an inducement, under favourable opportunities, to join their efforts for the improvement of the science to those by which it has been brought to its actual state. The obscure period during which astronomy was in its infancy, and in which the first notions must have been obtained from a mere view of the heavens, has been dwelt on at some length, and the probable nature of the earliest observations has been described. Some mention has, next, been made of the distribution of the fixed stars into clusters, of the dispositions of the principal circles imagined to be described on the surface of the celestial sphere for the purpose of marking with some precision the places of the sun, the moon and the erratic stars; and of the nature of the observations by which the periodical revolutions and, consequently, the mean motions of these may have been discovered before their places in the heavens could have been directly determined by instruments. An endeavour has, subsequently, been made to shew the nature of those assemblages of

spheres which were invented to exhibit some of the principal movements of the heavenly bodies, and to enable the astronomer to anticipate the more remarkable phenomena with tolerable accuracy. Then, after explaining from what causes the first systems ceased to answer the purposes for which they were imagined, some account has been rendered of the struggles between ancient prejudices and the evidence of newly discovered facts, the efforts made to accommodate the original hypotheses to the complex variations of the planetary motions have been noticed, and the historical sketch has, finally, been extended to the epoch at which the persevering spirit of man succeeded in detecting the laws which govern the movements of the great bodies in the universe Occasionally, the sentiments of the ancients on the principal points in the philosophy of the heavens have been introduced, and it will, no doubt, be agreeable to the reader to see those opinions collected which are thinly scattered in works not readily accessible to his enquiries. The contemplation of these subjects affords the satisfaction of observing how, from the first rude notions of unenlightened men, and through many slowly advancing improvements, the modern science has gradually attained its present eminence, and even a review of the false steps which have been taken, and by which its progress has been retarded, cannot be uninteresting to those who would minutely trace the operations of the human mind in the career of discovery.

That astronomy had been cultivated in the East to such an extent and in such ancient times as to permit, at an epoch more remote than that of the Noachian Deluge, the attainment of a very correct knowledge of the mean movements and places of the sun, moon, and planets, is an opinion which, during the last century, had several distinguished partisans, but which is, now, perhaps, nearly abandoned. Yet, as the idea is too remarkable and interesting to deserve entire neglect, it has been thought proper to notice it, in the following history, so far as to point out the circumstances on which it has been supported and the arguments by which it has been disproved. Some attempt has, also, been made to shew that, within the interval of two thousand years which elapsed between the establishment of the Chaldean

narchy and the age of Aristotle, it was possible, from obser-
tion, to discover all those elements of the celestial movements
iich are contained in the Hindu Tables, and to form those
nar periods which, soon after the time of the above philoso-
er, were known to the Greeks and which were, perhaps then,
st determined from the registers of observed phenomena, kept
Babylon or in Egypt during the said interval.

All the evidence which we now possess favours the belief that
e country between the Nile and the Euphrates is the birth-
ace of astronomy, the cradle in which it was nursed, and the
urce from whence it extended to other regions, and, though
written monument remains of the state of the science among
e first inhabitants of that part of the world, the reputation
hich they had acquired, and which, long after their nation
d ceased to exist, procured for those who professed to follow
eir doctrines the esteem and confidence of mankind is, in the
sence of such monuments, the best proof that can be offered of
eir early devotion to the study of the heavens.

One of the objects proposed in this Work is to give a distinct
count of the methods devised by the ancients for explaining
e observed inequalities in the celestial movements; and, as the
evelopment of the planetary systems is certainly due to the
reeks, who first adjusted the positions of the spheres, their
agnitudes and times of revolution, to the visible phenomena of
e heavens, the description of those systems is introduced in
e account of the Greek astronomy: no doubt, however, can
xist that, at least, the hypothesis of concentric spheres, which
ears the marks of being almost the earliest conception formed
om the apparent revolutions of the stars about the earth, was
vented by the Chaldeans, and it is even probable that this
eople did more than merely suggest the idea of such a ma-
hinery. It is natural that some curiosity should be felt to know
hy the results and computations founded on the ancient sys-
ems, now known to be erroneous in every respect, should, ne-
ertheless, have approached, in many cases, so near the truth,
nd it has, therefore, been thought convenient to enter so far
ito the explanation of those systems as to shew, from the ac-
ount delivered by Ptolemy, how the dimensions of the Defer-

ents and Epicycles, and the values of the equations arising from them, were determined. But the entire neglect into which the systems have fallen seems to render needless any more extensive development of the subject, which, however, is treated at length in the *Almagest*, and with considerable perspicuity in Delambre's History [a].

The astronomy of the ancients was founded on the practice of remarking the periodical returns of like phenomena, which, from their general regularity, in some measure supplied the place of theory; and, as the lengths of the intervals compensated the inaccuracies of the observations, it is evident that the mean motions of the sun, moon, and planets might be, thus, very precisely determined. Then, since the dimensions and motions of the spheres were so determined, by computation, as to represent the discovered inequalities when these were in a maximum or minimum state, it may be easily imagined that the differences between the observed and calculated places of the erratic bodies would never be great, and would often be incapable of detection by the instruments in use. The correct values of those inequalities, in the intermediate states, and several others now known to exist, by all of which the fallacy of the ancient hypotheses would have been demonstrated, were not till later ages discovered.

The Writer has attempted to trace with care the progress of astronomy among the Greeks. This people began the cultivation of the science with a knowledge of the elements obtained from the ancient observations made by the Chaldeans or Egyptians; and to them must be attributed the honour of having, first, applied the theorems of pure mathematics in the investigation of astronomical propositions. In fact, we perceive, in their writings, precisely that advance towards the discovery of the true laws of Nature which might be expected from men of lofty intellect, who seem to have been retarded in their career only by adhering with too much tenacity to a metaphysical notion concerning the perfection of the universe. The planetary systems of the Greek philosophers present an admirable display of ingenuity and address in their adaptation to the different movements which, down to the time of Hipparchus, had been ascertained; but the

[a] Hist. de l'Astron. Tom II.

attempt to represent the inequalities which more perfect observations afterward brought to light, necessarily gave rise to such modifications that the complexity of the machinery, at length, destroyed its utility. Some enlightened minds certainly entertained the idea that the revolutions of the celestial bodies were, in reality, very different from those which appeared, and even suggested, concerning those revolutions, an hypothesis comprehending the movement of the earth. But it required many centuries to vanquish the strong prejudices in favour of its quiescence, as well as to disabuse mankind concerning the fancied influence exercised by the stars on terrestrial substances; if, indeed, even now, it may be said that this last superstition has ceased to exist.

An account of all the processes employed in the modern astronomy, with the details of their discovery, could not be introduced in a work like the present without greatly increasing its bulk, and without entering into investigations which properly belong to a treatise on the science itself. But the ancient mechanism of the heavens, and the invention of the first rules for determining, by computation, the places of the sun, moon, and stars, form subjects differing, in every respect, from those which correspond to them in the actual theory of the universe. The Writer trusts, therefore, to have done that which will be considered neither uninteresting nor uninstructive, in shewing how the revolutions of a planet in a simple eccentric orbit about the earth were made to exhibit the alternately direct and retrograde movements observed in the former, and how its supposed revolution in an epicycle, about its mean place, produced the apparent changes of direction, and the principal variations of its velocity

Between the time of Ptolemy and the establishment of the Mohammedan power in Asia, astronomy appears to have been but little cultivated; a few commentators on the works of the Greek mathematicians and philosophers alone kept alive the science, which, moreover, was, during several ages, affected with errors perhaps before unknown, and arising either from great inaccuracies in the then observed longitudes of the fixed stars, or, which is more probable, from mistakes respecting the longi-

tudes assigned to them by the astronomers of some earlier age.

The Arabs, in their deserts, had always preserved a rude astronomy in connection with their worship of the "heavenly host," and it is probable that, when they attained political importance, they only prosecuted with more vigour, and more extensive means, a study, in which they had ever been interested. The duration of their science was limited by that of their empire; we are, however, indebted to them for preserving the knowledge acquired by the Greeks, for increasing it by a number of observations made with superior instruments, and for communicating it to the inhabitants of Western Europe.

The ancient Hindus, apparently, had claims to the character of a scientific people, part of their astronomy bears the marks of originality, and its foundations were, perhaps, laid in or near the times at which the Chaldeans and Egyptians are believed to have instituted the first measures for the cultivation of the science. It was, however, while the Arabian Khalifs occupied the throne of Bagdad that the first communication between the learned men of India and Syria, of which we have any distinct information, took place, though there is no reason to doubt that, after the conquests of Alexander had made India known to the Greeks, and during the reigns of that prince's successors, a constant intercourse subsisted between the same countries. The discoveries of Hipparchus at Rhodes or Alexandria might have been, then, conveyed to the banks of the Ganges, and, by the Hindu astronomers, incorporated with the elements of the science previously founded on the observations of their own predecessors: the results of Ptolemy's researches, also, if not immediately on their publication, were, at a subsequent time, probably along with the particular determinations of the Arabians, received and adopted by the same people.

No proof exists that the ancient Chinese cultivated astronomy as a science, the only monuments of the attention paid to the subject by the natives of the "celestial empire" being limited to a catalogue of phenomena observed by the eye, and to a few simple elements determined by means of the gnomon. the whole scarcely serving any other purpose than to shew that, in

the study of the heavens, the course pursued among this remote people was similar to that pursued by the western nations in corresponding circumstances. That such should be the fact cannot cause any surprise if we consider that the book of Nature is open to all, and that, therefore, all must, to a certain extent, read and reason alike. It is, however, worthy of remark that, besides an agreement in sentiment, among men in different ages and countries, concerning the visible phenomena of the universe, the principle of general attraction so extensively developed by Newton, was, two thousand years before his time, proposed as an hypothesis by the philosophers of Greece, and is found in the allegorical poems of the Hindus. Moreover, and the circumstance is equally worthy of observation, the metaphysical opinion of Berkeley concerning what is called material substance, that *its essence consists in being perceived*, is known to have been a fundamental tenet of the Vedanta school[a]. We may, therefore, allow, though it can by no means be positively affirmed, that both the Hindus and Chinese arrived at their astronomical elements independently of any other people; but, be this as it may, the want of authentic documents relating to their early histories and the great probability that much of their learning was drawn from foreign sources will, certainly, justify us in placing their astronomy after that of the Greeks

We are brought, next, to the times in which the writings of Ptolemy and his commentators were studied in Europe; and it will be seen that although, with general literature, astronomy began then to be assiduously cultivated in this part of the world, the authority of the Greek school of philosophy still held the minds of men in bondage, and that repeated efforts were made to represent the phenomena of the heavens by modifications of the ancient hypothesis even after the fallacy of the latter must have been manifest. Copernicus himself, who entirely changed the face of the science by considering the sun as the fixed centre of the orbits of the earth and planets, was not able to vanquish some of the ancient prejudices, and the planetary system proposed by him differs materially from that which is

[a] Sir William Jones's Discourses, Disc XI.

now, usually, called by his name The persevering labours of Kepler conspiring with the fortunate invention of the telescope, at length succeeded, however, in annihilating every impediment, and prepared the way for the present theory of the universe.

It will, also, be seen that the discoveries of the above astronomers were, by Newton, proved to be necessary consequences of a principle of nature which exists, identically, in the fall of a stone to the ground, in the tendency of the moon to the earth, and in those of the planets to the sun, and it is to be observed that from researches, founded on this principle alone, which were begun by our great philosopher, and extended after his death by the mathematicians of the continent, result the modern tables of the celestial movements. These exhibit, chiefly, the mean or uniform velocity which each planet would have if it moved in an undisturbed circular orbit, the first inequality of velocity, commonly called the equation of the centre, which expresses the variation arising from the movement in a supposed elliptical orbit; and the effects of the several perturbations produced by the attractions of other planets, by which the motion of each, both in longitude and latitude, is rendered still further variable, besides these, the tables contain the variable distances of the earth and planets from the sun, the movements of the apsides and nodes of their orbits, and all the corresponding elements of the satellites

Hitherto the improvements in analysis, by which the formulæ relating to the lunar and planetary motions were investigated, have been accompanied by corresponding ameliorations in the instruments of observation, and thus, the constant coefficients of the variable terms which enter into the formulæ have been obtained with considerable accuracy. But, that instruments more capable than those already in use, of determining accurately the places of celestial bodies by observation, should hereafter be constructed, seems very uncertain Instruments of great magnitude, though they afford superior optical powers, and are susceptible of more minute graduations than those of smaller size, are more than the latter subject to partial expansions or contractions, from inequalities in the material, and to derangements, from the strains produced by changing their

directions during the observation, and these evils, necessarily, place a limit to their useful dimensions. But we may add that the errors in the observed places of stars, arising from imperfection of vision and from inappreciable variations in the state of the atmosphere, too often render useless the skill displayed in the design, and the accuracy attained in the execution of the magnificent instruments produced by modern art

A history of the progress of astronomy would, probably, be thought incomplete if the actual state of the science were not described. Therefore, after exhibiting an outline of the researches of Kepler and of the planetary theory of Newton, the last, in all probability, to be recorded, some account has been given of the recent discoveries made in the heavens, of the operations undertaken to ascertain the figure of the earth, and of the nature of the instruments employed in observation and a chapter has been added, containing a statement of the subjects to which the modern analysis has been applied in investigating, by the theory of gravitation, the formulæ for representing the celestial movements

The Writer has not attempted, in the Work, to trespass on the domain of natural theology; and he only solicits the reader's indulgence while he remarks that astronomy affords the most striking evidences of the infinite power and intelligence of the Deity. The former is manifested in the incalculable number and vast magnitudes of the bodies in the universe, and the distances to which their attractive influences extend; the latter, in the proportion established between the intensities of the moving forces acting on each, by which, while in constant oscillation between opposing attractions, the planets constitute systems capable of an endless duration. That inconceivable tendency of all the particles of matter to approach each other, can only be considered as the result of a principle originally communicated to them purposely to be the bond by which the different parts of the universe might be held together. But, because this tendency, if it acted alone, would have caused all the particles to unite in one mass, the Divine Power, which gave existence and a law of attraction to matter, must, also, have been exerted in causing the unions of portions of that matter in many distinct

masses constituting suns and planets, in establishing the former as centres of particular systems, and in applying to each of the latter an impulsive force by which it is enabled to revolve about the common centre of the system to which it was made to belong. Here, then, are several independent actions which, since they are combined together to work out certain useful ends, necessarily exclude the possibility of a fortuitous occurrence. And though the profound geometer may determine the direction of the impelling force and the position of the point of application by which, for any planet, the particular motion in the orbit and the observed obliquity in the axis of rotation might be obtained, he is as incapable as the rudest peasant of shewing, from natural causes, what communicated the force, or why, among the infinite number of possible directions and intensities, those should have been given which, alone, are capable of producing the phenomena of summer and winter, of day and night, in unceasing alternation

It is evident that the science of astronomy may be treated in two very different ways. The observed circumstances, in respect of *time* and *place*, which attend the recurrence of celestial phenomena, by affording data for anticipating the repetition of the like phenomena in times to come, permit the laws which regulate the movements of the sun, moon and planets to be determined: or the existence of a law of nature, according to which material bodies may act on each other, being assumed; from this may be deduced formulæ expressing both the mean and variable movements, and agreeing with those obtained from a comparison of observations An astronomy formed from observation of the heavens is the subject of many excellent and well known English works, but the other, or that which is properly denominated Physical Astronomy, though now, perhaps, gaining ground, has, hitherto been but little studied in this country. If the first work of the kind, the "Principia" of the illustrious Newton, and the essays of Simpson and Robison, be excepted, reference can only be made to the treatises of the late Mr. Woodhouse, the learned researches of Ivory, Herschell, Airy, and Lubbock; and the valuable but, as yet, unfinished transla-

tions of the *Mécanique Céleste*, by Bowditch and Mrs. Somerville

To a treatise on astronomy founded on either of the two principles above mentioned the following Work will, it is hoped, serve as a convenient introduction, it may be considered as holding an intermediate place with respect to the voluminous histories of M.M Bailly and Delambre and, be it said, while acknowledging the merits of such as the elegant essay of Dr. Adam Smith, or that recently published in the Library of Useful Knowledge, the very general outlines which have, occasionally, been given of the origin and progress of the science.

Royal Military College, Sandhurst,
May 20, 1833.

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HISTORICAL ACCOUNT,

ETC.

CHAPTER I.

CAUSES WHICH LED TO THE CONTEMPLATION OF THE HEAVENS.

Sentiments excited by a view of the Firmament.—The worship of the celestial bodies was general, in the first ages of the World.—The positions of the celestial bodies were supposed to be indicative of physical and moral effects on the Earth.—Circumstances leading to the study of the heavens.—The probable origin of Astrology.—Agriculture and Navigation anciently regulated by observations on the phenomena of the heavens.—The necessity of anticipating the returns of the seasons.—Opinion concerning the existence of a very ancient Astronomy.—Alleged antiquity of Astronomy in the East.—Prejudice in favour of the antiquity of Eastern science.

THE brilliant spectacle which the celestial hemisphere exhibits when the Sun is pursuing his daily course within it, and when, from the same canopy, adorned with innumerable glittering points, the Moon displays her milder radiance, has always excited mingled emotions of pleasure and surprise in the mind of man. Nor do these affections alone appear to have attended the contemplation of the heavens. It is probable that man had from the first been instructed by express revelation, that the Universe is the work, and is subject to the government of a Being possessing infinite power and intelligence, but wanting a just conception of the true nature and attributes of the Creator, and being seduced by the splendour of the celestial host, he was soon led to regard, with reverential feelings, the Sun, Moon, and Stars, as appropriate symbols of that First Cause which he could only imagine to be supremely great and glorious.

In process of time these symbols, by withdrawing the attention from, and inducing an oblivion of the original object, usurped the place of that which they were, at first, intended only to represent Thus the Sun, Moon, and Planets began, themselves, to be considered as the real intelligences which govern the world; consequently, as having claims to the right of receiving divine honours: and they, then, were represented by terrestrial objects denoting their supposed qualities or attributes. Diogenes Laertius [a], asserts that the ancient Egyptians worshipped the Sun and Moon, designating them Osiris and Isis, and representing them by a Scarabeus, a Dragon, a Hawk or some other animal, and Diodorus Siculus [b], says that they considered those luminaries as the eternal and first gods: he adds that Osiris signifies *many-eyed*, and that the name was given in allusion to the rays which proceed from the sun in every direction and enlighten the earth.

The identity of Isis and the Moon is, however, doubtful, since, as Dr. Young observes, the name given by the Egyptians to the latter is masculine, which renders it unlikely that the luminary should have been worshipped as a goddess; but that a relation was supposed to subsist between Isis and the lunar influence is evident. Diodorus states that the Egyptians gave horns to the goddess, in order to express the cuspid appearance of the moon when she is in the increase and wane, and also, because an ox was consecrated to her. In Chaldea and the western parts of Asia, according to Herodotus [c], and Eusebius [d], the sun was worshipped as king of Heaven, under the name of Belus. In Persia [e] he was adored under the denomination of Mithras, and considered either as the image, or as the abode of Deity: and Lucian [f] states that there was in Phœnicia, a great temple dedicated to Astarte, who, as he was informed by one of the priests, was believed to be the same as the moon. In his second book, Diodorus Siculus also informs us that the Chaldeans assigned a Divinity to each of the portions into which they divided the zodiac, or path in the heavens apparently described by the Sun

[a] In Procemio

[b] Bibliothecæ Historicæ Lib I. sect. 11.

[c] Clio sect 181.

[d] Præp Evang Lib. I.

[e] Strab. Lib. XI. Plutarch. De Iside et Osiride

[f] De Syria Dea sect. 4.

in his annual course, and Plutarch, in the treatise above quoted, says they considered the seven planets as Gods, of which two were evil, two were good, and the remaining three were indifferent. The celestial bodies have, in all succeeding ages, been objects of adoration, and they probably will, in times to come, continue to find votaries, till the knowledge of the true religion has enlightened every nation of the earth The untutored savage still prostrates himself before the rising sun, or, with the observance of some religious rite, celebrates the principal phases of the changing moon.

Almost the first view of the face of nature must have shewn that the sun exerts a most powerful and beneficial effect upon the earth, by producing changes in the temperature of the air, in the processes of vegetation, and in the habits of animals: it must also have shewn that these effects depend upon the position of the sun in the heavens By analogy, therefore, it was not unreasonable to suppose that the moon and stars were productive of effects similar in kind, though perhaps inferior in degree, which might, like those produced by the sun, be ascribed to their situations in the heavens, and might, with respect to the moon, be conceived to vary with her change of figure These opinions being once entertained, it is probable that it would not be long before a propensity to trace effects to their causes would lead to an opinion that the celestial bodies were the powers by whose influence the bodies on the earth were endowed with the properties they are observed to possess, and which could not be accounted for by any discoverable agency. From hence the transition was easy to the belief that the sun, moon, and stars were the causes of, or were influential in developing the physical and moral qualities of man himself. Proofs of the existence of such opinions at an early time, are found in the works of several ancient authors: according to Diogenes Laertius[a], Hecateus of Miletus, who is supposed to have lived in the sixth century before Christ, in his treatise on the Philosophy of the Egyptians, ascribes to that people the opinion that the stars are of fire, and that by their influence all things in the earth are produced Sextus Empiricus asserts

[a] In Procem

also[a], that the Chaldeans conceived the seven planets to be the causes of whatever happens to men, and whatever is admirable on the earth. And Manilius, at the beginning of his poem, has the following line expressing the ancient and almost universal notion of the power of the celestial bodies on the lives of men:

———— "et conscia fati
Sidera, diversos hominum variantia casus"[b]

Since the perceptible influences of the two great luminaries in the heavens seemed to depend, in a great measure, upon their situations, which were distinguished by the neighbourhood of particular clusters of stars, it was also a natural supposition that these influences, as well as those of the planets, should be produced by the action of the heavens themselves, that is, probably, by the energies of the deities imagined to be there residing. In fact, we find that certain divisions of the heavens lying near the apparent paths of the sun, moon, and planets, were supposed to be the causes of heat or cold, dryness or moisture on the earth; and that the conjunctions of planets in those divisions were conceived to be indications of the physical effects to be produced by such powers in the heavens. Diodorus Siculus, in the second book of his history, asserts that the Chaldeans, from long continued observations of the stars, and from an exact knowledge of their motions, were enabled to predict future events, that they ascribed the greatest efficacy to the five planets, or, as they called them, interpreters, which, by their risings, settings, and conjunctions, announce to men the will of the gods, so that by an attentive consideration of the planets, this people, he observes, could foretell the occurrence of earthquakes, tempests of wind and rain, and all the various phenomena of the atmosphere, as well good as evil, to which he adds, the eclipses of the sun and moon, and the appearances of comets.

But the changes affecting the constitution of the earth itself were supposed to depend, in like manner, upon the aspects of the heavenly bodies, for we are told by Seneca, that a certain Berosus (a Chaldean philosopher, whom he supposes to have been contemporary with Belus) had predicted a conflagration

[a] Adversus Math cap 21. [b] Astronomicon, Lib. I. ver. 1

and deluge, both of which were to be universal; the former, to take place, when all the planets were in conjunction in Cancer, and the latter, when in Capricorn, and in later times, a disciple of Albertus Magnus pretended to find by computation that, before the Noachian deluge, there was a conjunction of Saturn and Jupiter in one of the supposed watery signs, by which, he said, that catastrophe might have been foretold.

The opinion that the earth, or rather the physical condition of its surface, has been many times successively destroyed and renewed, originated, probably, in the observation that the revolutions of the sun regularly brought with them a return of the seasons in the same order, whence it might be inferred, as soon as it was known that the stars assumed nearly the same arrangements at the end of certain intervals of time, that the arrangement which existed at the commencement of the present state of the earth would again exist at its termination, that a new state would afterwards arise which, in like manner, would, after some certain interval, also come to an end, and so on for ever The conjunctions of planets were, naturally, at first, considered as causes or signs of these changes; and when the precession of the fixed stars became known, the time of their revolution was, as firmly, believed to coincide with the duration of each terrestrial period

The conjunctions and oppositions of planets and the appearances of remarkable stars were also, till the birth or revival of sound philosophy, considered as causes or tokens of changes about to take place in political societies. The comet, for example, which, to the eye of superstition, appeared suspended like a sword over Jerusalem before its destruction by Titus and the ruin of the Jewish nation, has been often quoted as a presage of the horrors that were soon to overwhelm that devoted city and people.

From the poem of Manilius which abounds in doctrines relating to the celestial influences, drawn from notions very anciently prevalent, we learn that the parts of the heavens, lying in and near the Zodiac, which happened to appear above the horizon at the birth of a child, were supposed to determine his

character and fortune during life[a]. But the interest of the human race in the regions beyond the earth was not solely derived from the opinion that man is the subject of a temporary influence from thence. Those regions were in early times considered as his proper abode: ignorant of his origin, Vanity suggested the fancy that his ancestors descended from the heavens or from the celestial bodies they contain; and Hope inspired the idea that, after death, he should there rejoin the spirits of those to whom, on earth, he had been attached by sentiments of esteem and affection.

Independently of the interest excited by the phenomena of the heavens from the causes just mentioned, we can conceive that the important advantages derived from the sun as a regulator of the operations of husbandry and the affairs of the pastoral life, from the moon which supplies the place of the sun by night, and from the stars which enable the traveller to direct his course across the pathless desert or ocean, must have led, early, to the study of the appearances and movements of the celestial bodies. Thus originated the science of astronomy, which the ancients seem to have connected with almost every thing useful in society. It teaches, observes Clemens Alexandrinus[b], the figure of the universe, the revolutions of the heavens, and the risings and settings of stars; by it are discovered the returns of the seasons and the changes of the air, and on it depend the arts of navigation and architecture, and before his time it had been remarked that astronomy was not less necessary to the military art than to agriculture and navigation[c]. It may be added, that astronomy was soon incorporated with the religions of the heathen world by the priests, who were some of the first observers, and it is probable that much of the fabulous history of the gods and heroes consists of allegorical descriptions of the phenomena of the heavens, and of the operations of nature on the face of the earth.

Man being stimulated by a perpetual desire to improve his physical and intellectual condition, being gifted by his Maker

[a] Astronomicon, Lib. IV. V.
[b] Stromatum, Lib. VI.
[c] Plato, De Republica, Lib. VII. Polyb Lib. IX.

with the faculty of recalling, in imagination, events passed away, and of anticipating those which are to come; being also acutely sensible to the fear of misfortune and the hope of happiness, the removal of the veil which has been drawn by Providence between the present and the future is, naturally, an object of his earnest solicitude. And, it being supposed that the accomplishment of this end was capable of attainment by a right interpretation of the book of nature, exhibited in the skies, the phenomena of the heavens were attentively studied for that purpose; this gave birth to the vain profession of astrology which, holding out the prospect of gratifying one of the strongest propensities of human nature, was from the earliest time, cultivated with ardent zeal. The practice of foretelling future events by the stars, which is founded on the opinion that man is a passive being and that his moral as well as physical condition is subject to the influence of the material heavens, consequently the result of necessity, continued to prevail throughout the civilized world till the last century when, by a general diffusion of the knowledge of the true system of the universe, its absurdity became manifest; and the art being overthrown by the united arms of reason and ridicule, its adherents have, since, ceased to be considered otherwise than as dupes or impostors.

The various offices to which the visible phenomena of the heavens were made subservient, early gave rise to the institution of a class of men for the purpose of watching the risings and settings of stars. The vigils of these persons happily procured an accumulation of facts which, while they at first only contributed to the advancement of some of the useful arts, were destined to be the materials by which astronomy was, in after ages, to be raised to its present lofty station and rendered the most stupendous monument of human intellect.

Indications have been drawn from the Book of Job, and particularly from that passage in which the Deity, when vindicating his power, calls on the Patriarch to say if he can bind the delights of *Chimah* and loosen the bands of *Chesil* [a], to shew that the people of the East very anciently paid some

[a] Ch. XXXVIII.

attention to the phenomena of the heavens on account of their connexion with the vicissitudes of the seasons. Now those terms are, by the Septuagint, taken for the names of stars or constellations, for they have rendered the former by *the Pleiades* and the latter by *Orion*, and though it is true that the particular stars or assemblages of stars which the terms indicate, are uncertain, yet the sense of the passage seems to require that they should be such as have some relation to the effects of the sun on the earth in opposite seasons of the year. Parkhurst, however, conceives that *Chimah* may be intended to signify the heat of summer, by which all the delicacies of nature are produced, and the bands of *Chesil*, the winter's cold, which restrains their development; but this ingenious explanation can scarcely be received without hesitation on account of the improbability that, in the age of the LXX, the knowledge of the precise meanings of the Hebrew words, should have been so far lost that men, learned in the language, could mistake those used to express heat and cold for the names of celestial bodies or figures. If we consider *Chimah* to signify the Pleiades, and if, with M. Bailly [a], we infer, from thence, that the effect produced by their "sweet influences" means the genial spring, whose return might, in those days, he supposes, be accompanied by the heliacal rising of that cluster, or its first appearance in the east a short time before sun-rise; it would seem to follow that *Chesil* signifies some constellation, as Scorpio, which, by the presence of the sun in it, was supposed to produce an effect on the seasons contrary to that which takes place when the luminary is in Taurus. Bailly, pursuing his idea, imagines that the rising of the Pleiades with the sun coincided, in that age, with the arrival of the latter at the vernal equinox, that is with the commencement of the spring, and he finds by computation that, in the latitude of the place where Job is supposed to have dwelt, the phenomenon occurred about the year 3900 Before Christ; it would follow, if the interpretation and hypothesis were just, that the time at which the Patriarch lived, or in which the Book bearing his name was written, was anterior to the epoch usually assigned to the Noachian deluge.

[a] Astronomie Ancienne Eclaircss. Liv. IX. sect. 8

It must, however, be admitted that determinations founded on such uncertain premises are any thing but conclusive.

The writings of the Greek and Latin poets afford many evident proofs of the importance attached, by the ancients, to the study of certain celestial phenomena, on account of their connexion with husbandry and navigation. Hesiod, the earliest author whose precepts concerning rural affairs have reached our times, says that corn should be reaped at the [heliacal] rising of the Pleiades, and that the ground should be ploughed at their [heliacal] setting.

> Πληιάδων Ἀτλαγενέων ἐπιτελλομενάων,
> Ἄρχεσθ' ἀμητοῦ ἀρότοιο δὲ, δυσσομενάων.
> Αἳ δή τοι νύκτας τε καὶ ἤματα τεσσαράκοντα
> Κεκρύφαται [a].

Now Hesiod is supposed to have lived about the year 900 B. C., and the situation of this cluster will be found, by astronomical formulæ to have been then such that its heliacal rising, in Greece, must have taken place forty-three days after the vernal equinox, a time of the year corresponding to about May 7 in the present age but the harvest now commences in that country in the beginning of June, we must, therefore, suppose that the season in which the corn ripened in Greece, was earlier in the time of Hesiod than it is at present. The heliacal setting of the Pleiades, or their disappearance in the west soon after sun-set, which served to designate the time for ploughing, took place, at the above epoch, four days after the vernal equinox: and, consequently, the interval between the heliacal setting and the heliacal rising, next following, was about forty days, during which time the cluster was invisible from its proximity to the sun.

In the poetical description of the heavens given by Aratus [b], who professes to have paraphrased a work of Eudoxus composed about the year 370 B. C., the fields are said to be void of corn, or the harvest was finished, when the sun entered Leo, and this, in the age of the last mentioned astronomer, must have been about seventeen days after the summer solstice, [July 12,]

[a] Opera et Dies, ver 383. [b] Arati Phænomena.

a circumstance which seems to confirm the opinion drawn from the precepts of Hesiod, concerning the time of harvest in Greece. The season of the vintage is said, by Hesiod[a], to be when Orion and Sirius are in the mid-heaven, and when Arcturus rises with the sun, and if the longitude and latitude of Arcturus be obtained from astronomical formulæ for the year 900 B. C, it will be found, by computation, that the heliacal rising of this star took place about eighteen days before the autumnal equinox, that is, about September 7 according to the present reckoning.

In his precepts concerning navigation, Hesiod states[b] that fifty days after the conversion of the sun in summer [summer solstice], the weather is favourable for sea voyages. Aratus also observes[c] that when the sun is in Leo, which was, in his time, about the same season of the year, the Etesian winds tend to the sea and the use of oars on ship-board may be superseded by that of sails, and, in fact, the periodical north-winds prevail at present in the Levant, at that season. On the other hand, Hesiod observes[d], that, when the Pleiades rise from the dark seas, sailing is dangerous, and, on account of the violent winds and rain, it is necessary to sail in large vessels well provided with stones, [for ballast,] and to work much at the pumps. The rising of the Pleiades here alluded to is, no doubt, that called *acronical*, which takes place at the setting of the sun, and, in the days of Hesiod, it must have happened fourteen days after the autumnal equinox [Oct. 8], when, and during the winter, it is known that, at present, the south winds prevail in the Grecian seas, accompanied by storms of thunder and lightning. Aratus[e], designating the unfavourable season for navigation, remarks that when the sun is in Sagittarius, and the Scorpion rises heliacally, ships must not sail by night Now it must be observed, that, in the age of Aratus, the sun entered Sagittarius about sixty days, and, in that of Hesiod, about fifty days, after the autumnal equinox; it is probable, therefore, that Hesiod meant to express the commencement of the season, and Aratus, the time when the violence of the winds was the greatest

[a] Opera et Dies, ver. 609. [b] Ibid. ver. 612. [c] Phænomena.
[d] Opera et Dies, ver. 618. [e] Phænomena.

The first book of the Georgics abounds in precepts relating to husbandry At ver. 219 the poet directs that the soil should be prepared for corn when the Pleiades set in the morning [acronically], and the bright star in the Corona Borealis rises [heliacally], phenomena which, in the time of Virgil and in the latitude of Rome, took place, respectively, on the thirty-sixth, and about the fifteenth day after the autumnal equinox. Also, at verses 215 and 227, he recommends that tares and pulse should be sown both when Canis [Major], and when Bootes, probably meaning the star Arcturus, set with the sun [heliacally] The first of these phenomena must have occurred about thirty-seven days after the vernal equinox [April 30], and the latter about forty-five days before the winter solstice [Nov 9]. Several rules for anticipating the weather are given at verse 424, and, in the Æneid, allusions are made to the indications of approaching tempests and rains drawn from the [heliacal] risings of Orion and the Hyades.

"Cùm subitò assurgens fluctu nimbosus Orion"[a]

And,

"Arcturum, pluviasque Hyadas, geminosque Triones"[b].

The rising of Orion, in the age of Virgil, took place about sixteen days after the summer solstice, and that of Arcturus about sixty days after the vernal equinox. Ovid, in the Fasti, draws the like indication from the setting of Bootes at sun-rise, which is nearly coincident, in time, with the last mentioned phenomenon. Various references to the risings of stars, in connection with agriculture, are also to be found in the work of Columella[c], but the phenomena, as well as some of those mentioned by Virgil, appear to belong to an earlier age, and, probably, the Roman authors, in ignorance of the changes produced in the times of their occurrence by the slow displacement of the equinoctial points, have introduced into their works the results of the observations of Eudoxus or some more ancient astronomer without noticing that they had ceased to correspond with the actual state of the heavens.

Sophocles ascribes to Palamedes, one of the heroes of the Trojan war, a knowledge of the courses of the stars, the [daily]

[a] Æneidos Lib. I. ver. 539 [b] Ibid. ver. 748. [c] De Re Rustica, Lib. IX.

revolution of the Bear and the setting of the Dog star, and this knowledge he is supposed to have imparted to the Greeks for their use in navigation[a]. From Aratus[b] we learn that the Phenicians made use of the stars of Ursa Minor, which, though less brilliant than those of Ursa Major, afforded a more certain indication of the northern part of the horizon on account of their greater proximity to the pole: and this circumstance, which is alleged as a proof of the superior science of the Phenicians, is confirmed by the following verses of Callimachus[c].

> Καὶ τῆς ἁμάξης ἐλέγετο σταθμήσασθαι
> Τοὺς ἀστερίσκους, ᾗ πλέουσι Φοίνικες.

Manilius, also, speaking of Ursa Major and Minor, says they occupy the extremity of the earth's axis [in the heavens], and guide the mariners over the vast sea.

> "Summa tenent ejus miseris notissima nautis
> Signa, per immensum cupidos ducentia pontum." [d]

The above quotations may suffice to prove that, at an early period, motives were not wanting to induce men to study the visible phenomena of the heavens with considerable attention

In the first ages of the world the circumstances requiring a knowledge of celestial phenomena must have been but few, and the observations which then could have been made, must, necessarily, have been of the most simple kind. Though we have no positive knowledge of their nature, yet, from what we can imagine of the wants of men emerging from a state of complete barbarism, we may safely conclude that they consisted in noticing, at night and morning, such risings and settings of stars as those above mentioned But it is easy to conceive that it would not be sufficient to know, by the heavens, the arrival of the season for the performance of any of the labours of agriculture, or for undertaking a voyage to some distant country; it would also be necessary to ascertain long before hand when such seasons would occur, that time might be afforded to make the necessary preparations for the work or the navigation: and we can imagine that it would be indispensable to know, nearly, the times of the returns of heat or cold in order to be enabled to

[a] Achilles Tatius, Isagoge ad Phæn. Cap I in the Uranologia of Petavius.
[b] Phænomena. [c] Diog. Laert. in vita Thal. [d] Astronomicon, Lib. I. ver. 301.

take the requisite precautions against the inconveniences they produce. A few successions of summer and winter would suffice to shew that the returns took place at the end of nearly equal intervals of time, for which the number of risings and settings of the sun would afford a measure, and it would, hence, no doubt, be early attempted to keep a register of such phenomena for the purpose of acquiring more readily a knowledge of the recurrence of the seasons, the importance of which, in many respects, would render it desirable that they should be anticipated with some degree of precision.

The exact period to which the infancy of astronomy should be referred has been a subject of serious dispute, the progress of the science, in Greece, from a state of extreme simplicity, can be distinctly traced in the biographical accounts we possess of the first philosophers of that nation, and in the writings of those among them who, subsequently, devoted themselves in a particular manner to the study of the movements of the heavenly bodies: and, though the earliest notices of these subjects, in the Greek authors, are accompanied by indications that they were drawn from more ancient sources in Chaldea and Egypt, yet there is nothing in them to shew that, in the latter countries and in those times, the science had advanced beyond its first elements: hence it has been almost universally concluded that the origin of astronomy, like that of all the arts essential to the convenience of man, may be referred to a period subsequent to that which, from the evidence of authentic history, is usually considered as the epoch of his first abode on the earth. But circumstances, related in the works of some of the Greek historians, and certain documents brought within the last century from the East, have given rise to an opinion that, in an age far more remote, astronomy, in all that concerns the observed motions of the sun, moon, and planets, was in a state of perfection, capable of bearing comparison with that of the present day. This hypothesis has been maintained both in France and Britain with great plausibility of argument; but, not only have recent investigations made it evident that the reasonings by which it was supposed to be established are entirely inconclusive, in order to reconcile the hypothesis with the present low condition of the

science in those parts of the world where, in times antecedent to any of those referred to in history, it is supposed to have been so highly cultivated, it has been assumed that some great revolution has destroyed the once existing monuments of that ancient learning, and even of the nations themselves, among whom it is pretended to have flourished; an assumption, for which, it is needless to say, there is not the least foundation.

The historical evidences which have been alleged in favour of this very ancient astronomy, are those furnished by Diodorus Siculus, who [a] observes that the Chaldeans pretend to have made observations of the stars during a period of 473,000 years previously to the expedition of Alexander into Asia, by Diogenes Laertius, who asserts [b] that the Egyptians reckoned 48,863 years between the reign of Vulcan and that of Alexander, during which they had observed 373 eclipses of the sun, and 832 eclipses of the Moon, and by a passage in Pliny [c], which, when corrected, shews that the Babylonians had made celestial observations during a period of 720,000 years, according to Epigenes, and of 490,000 years, according to Berosus and Critodemus. The antiquity which these periods, if considered as real, would oblige us to assign to the origin of astronomy, and consequently of the human race, though enormously great, is not more extravagant than that which is implied in the fictitious chronologies of the Eastern nations. If we turn to Eusebius, we find [d] that, according to the relation of a real or pretended Berosus, between Alorus the first king of Chaldea, and Xisuthrus, under whom occurred a great deluge, which, as Eusebius supposes, was that mentioned by Moses, there had elapsed 120 sari, each of which is said to have been equal to 3,600 years, and the whole interval to 43 myriads of years [432,000]. It is also related in the same work, on the authority of Manetho, an Egyptian priest who lived in the reign of Ptolemy Philadelphus, that the first sovereign in Egypt was the Sun, after whom followed in succession, Saturn, Osiris, Horus, and others, till the throne was filled by Bitis; and that the whole extent of the period during

[a] Biblioth. Hist. lib. II.

[b] In Prooemio.

[c] Nat Hist. lib VII cap 56

[d] Chronicon, Pars I.

which this race of kings reigned, who are designated principal deities, was equal to 13,900 years: to them succeeded the races of demi-gods and Manes, who respectively governed the country during 5,212 and 5,813 years, when Ægyptus established a new dynasty; so that the whole number of years elapsed between the reign of the Sun and that of Ægyptus, who is supposed by Eusebius to have been the same as Miziaim the son of Ham, was 24,925 The historian Syncellus agrees with Eusebius in the duration he assigns to the Chaldean monarchy, but the former makes the interval from the reign of the Sun, in Egypt, to that of Nectanebus (about 350 years before Christ), equal to 36,525 years: all these numbers, however, fall far short of those which are presented to us in the writings of the Hindus, where the three first ages of the world include, it is pretended, an interval of 3,888,000 years, which is supposed to have terminated with the year 3102, B.C [a] The mind recoils from the contemplation of these immense periods, unbroken by a single trace of the works of man, which, according to the hypothesis, must have passed away with the accumulated treasures of art and science, and must have left the men of succeeding times to begin the career of discovery as though the race had, at the origin of the present state of things, been first called into existence.

The improbability that all the discoveries made during such long successions of ages could be completely sunk in oblivion, affording at once an argument against the reality of those periods, it seemed to follow, either that the periods were unfounded fictions, or that the term year, which serves as the unit of their measure, represents some certain portions of time different from that to which it is now constantly applied. The first of these two opinions would, perhaps, be thought to remove the difficulty too easily, the latter is rendered highly probable by the consideration that a year signifies any revolution of time, and that it was a very common practice among the ancients to assign the same denomination to divisions of time, of very different lengths: Eusebius asserts [b] that the years of the ancient Egyptians were

[a] Bailly, Astronomie Indienne, Disc. Prelim. page lxxix.

[b] Chronicon, Pars I.

called lunar, and that each consisted of thirty days; this value he applies to the years in which he has expressed the duration of the Egyptian monarchy, and multiplying the number of them by $\frac{30}{365.25}$, he finds them equal to 2,047 solar years, which he conceives to agree nearly with the Hebrew chronology. Diodorus Siculus, speaking of the duration of the world [a], says, the years by which it was expressed consisted of three months each, and his assertion is confirmed by Censorinus, who states [b] that such years were first formed by Horus, and were frequently used by the Egyptians, the latter also adds that the Carians and Acarnanians had years of six months each. A passage quoted by Syncellus shews that the Egyptians also gave the name of year to the space of one day; and among the ancient Hindus we find traces of years consisting, each, of fifteen days [c], of one day, and even of a small fraction of a day. Now by employing one or another of these values of a year according to circumstances, M. Bailly, and others, have endeavoured to reduce the lengths of those great periods within the limits of probability, but it must be admitted that the adaptations are often arbitrary, and the subject will certainly be for ever involved in the deepest obscurity.

Bailly divides the period of 36,525 years quoted above, from Syncellus, into four parts, of which the first constitutes the duration of the reign of the Sun in Egypt; the second, that of the twelve principal deities, and the third is assigned to the eight demi-gods and the sovereigns who preceded Nectanebus. He considers each of the years in the first division to be equal to the time of a sidereal revolution of the moon; each of those in the second division to consist of three months, and all the rest to be really solar years, the sum of the years, in the three divisions, when thus reduced, gives 5,782 years from the commencement of the reign of the Sun, or from the origin of the Egyptian monarchy, to the time of Nectanebus [d]. In like manner, the period of 48,863 years, which is stated by Diogenes

[a] Biblioth. Hist lib I. [b] De die natali, cap. 16.
[c] Quintus Curtius, lib. VIII. cap 9.
[d] Astronomie Ancienne Eclairciss. liv. I. sect 13.

Laertius to have elapsed between the reigns of Vulcan in Egypt, and of Alexander the Great, is reduced, by Bailly *, to 5807 years, and the 120 sari of Berosus are reduced to 2151 solar years, by supposing, with Suidas, that the saros is equal to 18½ lunar years, of 354 days each. The 720,000 years supposed by Epigenes to have elapsed since the Chaldeans began the practice of observing the stars, being considered by Bailly † as years of one day each, are equal to 1971 solar years, a number coinciding with that assigned to the period within which were contained the celestial observations said to have been made at Babylon, and which, according to Simplicius ‡, were sent by Callisthenes to Aristotle. With respect to the Hindu period above mentioned, M. Bailly supposes § that the years of the first age were, each, equal to half a day, and those of the second and third ages to one-eighth of a day, by which the real duration of the three ages is made equal to 3104 solar years; and, as these terminate in the year 3102 before Christ, it would appear, if the hypothesis were admissible, that the ancient Indians supposed the commencement of the present state of the earth to have been in the year 6206 before the Christian era, which does not differ much from the two epochs found, as above stated, on reducing the periods given by Diogenes Laertius and in the Egyptian chronicle.

Additional arguments in favour of the opinion of a very ancient astronomy have been drawn from the denominations said to have been assigned to the zodiacal constellations by the Egyptians, and, also, from the astronomical tables which, in the last century, were brought from India to Europe. The names of the constellations being imagined to express the principal circumstances which have relation to the climate and agriculture of Egypt when the sun is in each constellation, respectively, and the conformity of the figures to the subject signified being found to have held good about 15,000 years before the present time, it has been boldly asserted that the Egyptians were, then, a people skilled in astronomy; and, consequently, that they must have

* Astronomie Ancienne Éclairc., liv. I. sect. 14. † Ibid. liv. [illegible] sect. 2.
‡ Comment. de Cœlo, lib. II. § Astronomie Ancienne Éclairc. liv. I. sect. 1[illegible].

cultivated the science from a period still more remote. The tables profess to shew the places of the sun, moon, and planets at a period which ascends to above 3000 years before Christ; and, as it is supposed that these places were determined from observations which therefore must have been continued during many previous ages, it would follow that the origin of the science in that country must have been long antecedent to the epoch of the tables themselves.

Thus the relations of unauthenticated traditions; inferences drawn from an unfounded surmise; and astronomical tables pretending to have been founded on phenomena actually observed, but which may, as probably, have been formed by computations of the periods of phenomena for times past, from data furnished by observations made in a comparatively recent age, are taken for proofs of antiquity sufficiently convincing to outweigh all the evidence which written history has conveyed to us: though it may with equal probability be asserted that the traditions and the tables originated only in the vanity of a people who thought its national glory was enhanced in proportion as the commencement of its political existence was referred to a remoter era.

The acquiescence of some of the most enlightened philosophers of Europe in the claims of the eastern people to the reputation of possessing a highly cultivated astronomy at such distant periods was, perhaps, owing to their knowledge of the fact, that the East was the seat of learning at times when the people of Europe were in a state of barbarism, and to a prejudice excited on being made acquainted, for the first time, with monuments of science obtained from distant regions, and of unknown dates, but appearing, evidently, to be the works of a more industrious and more polished race of men than those now occupying the countries in which they were found. And as objects which appear remote and ill-defined to the eye, are, by some error of judgment, usually supposed of greater magnitude than when distinctly seen, so, to whatever has its origin concealed in obscurity, we, by a similar prejudice, always assign an antiquity beyond that of the events which have been transmitted to us by the stream of authentic history; thus the mystery hanging over the epochs of the works in question, is, in a great

measure, the cause that a superior antiquity has been ascribed to them than they, in reality, deserve.

Without staying, then, to form conjectures concerning the state of astronomy in times antecedent to the oldest referred to in written history; because, to dwell upon that which, if it ever existed, is now certainly lost, can be productive of neither pleasure nor profit, we proceed immediately to trace the rise and progress of that astronomy which has been for many ages so successfully cultivated in Europe, and, fortunately, for attaining this end, there exist materials enabling the enquirer to ascend to its very origin.

CHAPTER II.

THE FIRST NOTICES CONCERNING ASTRONOMY.

Possibility of an Astronomy before the Noachian Deluge.—Ancient discoveries inscribed on columns.—Astronomy supposed to have been cultivated in Chaldea and Egypt.—Notions entertained of the earth's figure by the Greeks, the Persians, and the Hindus.—Opinions of the ancients concerning the nature of the universe.—The tower of Belus and the Egyptian pyramids supposed to have been used as observatories.

THE science whose first dawnings it is now proposed to exhibit professes to acquaint us with the constitution of the universe itself; by it man may, in idea, leave the comparatively diminutive spot to which, during his natural life, he is confined, and, within the boundless regions of indefinitely extended space, may measure the distances and magnitudes and, even, weigh the masses of the remotest planets, and, leaving them, can ascend to distances compared with which those of the planets from the earth decrease till they become insensible points, where he may contemplate the arrangement of innumerable orbs which the most powerfully assisted vision can, here, but dimly discern. By this science some of the deepest rooted prejudices of the human mind have been eradicated, and man has learned to disbelieve the most perfect of his senses; he has been forced, by indubitable evidence, to admit that the solid and, seemingly, quiescent earth, with all the magnificent works of art and nature on its surface, is incessantly whirled with vast rapidity about the sun, and that the motions he daily observes in the heavenly bodies are, in most cases, directly the opposites of those with which they are really endowed, instead, also, of regarding the earth as the chief object in the universe, and the sun, moon, and stars as formed only in subservience to it, he is made to perceive that he occupies one of the least orbs in the system: that, in fact, he is a native of one of the smallest provinces belonging to the great empire of heaven.

If the knowledge we, at present, possess, of the system of nature, be compared with the ignorance which for ages pre-

vailed respecting it, it will be impossible not to feel proud of the success which has attended the recent exertions of the human intellect; but this feeling will not be unaccompanied by a humiliating regret on considering how impossible it is for us, in this life, to become in the least degree acquainted, except by the feeble light of a doubtful analogy, with the nature and properties of the infinite varieties of objects with which no one can hesitate to believe that it has pleased the Deity to furnish the celestial orbs, as he has furnished the earth we inhabit, nor can this regret receive any alleviation but from the hope that the immortal spirit of man is destined to advance continually towards perfection, and to proceed as far as created beings may be permitted to go in the investigation of the Creator's works when, in new states of existence, it shall be endowed with the faculties necessary to enable it to comprehend them

Independently of the direct testimony of Josephus, which, indeed, we ought to be careful not to consider as of any great weight, it may be considered highly probable, from the propensity of man to seek information concerning the objects about him, and from the traces still existing of ancient observations made in the East, that the inhabitants of the antediluvian world had acquired some knowledge of astronomy; and it may, even, be admitted that some written or traditional account of their discoveries was transmitted to those who, subsequently, founded the first monarchies in the East, through the survivors of the dreadful catastrophe which put an end to the previous state of things on the earth, it may, therefore, be safely concluded that, after the deluge, the natives of the Syrian and Egyptian plains had not, entirely, to create the science anew. But, in the absence of any information concerning the learning of the men before the Flood, and from the rude notions which seem to have prevailed during several ages after the renovation of the human race, we may, without impropriety, consider astronomy as in its infancy when the posterity of Noah left the residence of their father and established themselves in the three great regions which then constituted all that were known of the earth

The passage in Josephus relating to the existence of astronomy among the antediluvians is contained in the second chapter of the first book of his History, where the writer states that the descendants of Seth were endowed with good dispositions and applied themselves to the contemplation of celestial subjects: he adds that, since Adam had predicted the destruction of all things on the earth, once by the violence of waters and, again, by the action of fire, they, lest the knowledge of these subjects should be lost to those who might survive the deluge, constructed two columns, one of brick, and the other of stone, and inscribed their discoveries upon them. Josephus alleges that one of these columns existed, in his time, in the country of the Seres, but where that country was situated is now unknown; and, as best suited the purpose of modern authors, it has been supposed to be some district either in Upper Egypt, Syria or in the north-western part of India. Before the use of paper or parchment, the practice of engraving, on stone or metal, the relations of remarkable events, moral precepts and scientific discoveries was, necessarily, general; and hence we so often find among the ancients mention made of inscriptions on columns: besides the instances above-mentioned we may observe that, according to Epigenes, the Babylonians preserved the accounts of their observations concerning the stars on stones or bricks[a]; and Diogenes Laertius relates that Democritus had transcribed his moral discourses from the sculptures executed on a pillar in Chaldea. Achilles Tatius[b] also names the Egyptians as the first people who measured the heavens and the earth, and adds that they wrote the result of their researches on columns in order that they might be transmitted to posterity; and Eusebius[c] quotes a passage from the works of Manetho, in which the writer asserts that he had travelled into the Seriadis, or the country of the Seres, in order to examine certain inscriptions, in hieroglyphical characters, traced on columns which had been raised in that country, probably in some part of Egypt, by Thoth, or Hermes. Nothing

[a] Pliny, Nat. Hist. Lib. VII. Cap 56.
[b] Tatius, Isagoge, Cap. I. in Petav. Uranolog
[c] Chronicon, Lib. I.

is known of the nature of these inscriptions, nor of the Hermes by whom it is said they were executed; but Syncellus supposes, on no certain foundation however, that he lived before the Deluge. The resemblance between the words Seth and Sothis has led to an opinion[a] that Josephus took his account of the columns erected by the antediluvians from the original work of Manetho, and this is not impossible, it may, even, be suspected that the prediction which the Jewish historian has put in the mouth of Adam is the same as that of the destruction of the earth by a deluge and conflagration, which, by Seneca, is ascribed to Berosus.

Whatever may be thought of the tradition related by Josephus and the inscriptions of Hermes, it is certain, from the testimony of ancient authors and from the known taste of men for the contemplation of the visible heavens, that some notions concerning astronomy must have been acquired immediately after the Flood by those who first, in Chaldea and Egypt, united themselves in societies. Philo relates that Terah, the father of Abraham, was skilled in Astrology. Josephus[b] makes the Chaldean philosopher Berosus assert that Abraham was a man of acute mind, that he instructed the Egyptians in arithmetic and in those things which appertain to astrology and astronomy; and he infers that these sciences were, first, transmitted from the Chaldeans to the Egyptians, from whom they afterwards passed to the Greeks. But no particulars have reached us concerning the state of the sciences in the days of those Patriarchs, and we shall hardly be justified in allowing that more of astronomy was then known than a few facts relating to the seasons, or the times of the rising and setting of some of the stars, as much as this may be conceded, for it might easily be obtained from observations made by the naked eye.

The opinion that the first elements of astronomy were originally brought from Chaldea to Egypt seems to be confirmed by a passage in the fifth book of Diodorus Siculus, where it is said that the Heliadæ, or descendants of the sun, a people thus designated, no doubt, because they came from the East, excelled

[a] Weidler, Hist. Astr.

[b] Josephus, Antiq Lib. I. cap 8

other men in knowledge, particularly in that which relates to the stars, that, by them, the art of navigation was cultivated and the hours divided into certain courses, [probably meaning that the day was divided into hours,] and that Actis, one of this race, arriving in Egypt, built Heliopolis and gave to it the name of his father It is added that, according to the general belief, the Egyptians acquired from him a taste for astrology, which, by ancient authors is generally confounded with astronomy, and that this people afterwards cultivated the science with so much assiduity as to be considered its inventors On the other hand, Tatius[a] asserts that the Chaldeans obtained their knowledge of astronomy from the Egyptians and ascribed to Belus the merit of introducing the science into their own country.

The claims of the Egyptians to the honour of the first discoveries in astronomy are also mentioned by Diodorus, who alledges[b] that the people of Thebais pretend to be the most ancient of men, and the inventors of letters and astrology, he adds that they professed to be acquainted with the situation of the earth, and the risings and settings of stars, and to have arranged the order of days and months He asserts that they appear to have observed accurately the eclipses of the sun and moon; but their merit, in this respect, is rendered suspicious by the pretensions he says they made to the art of divination from celestial phenomena, and to the power of predicting with certainty every future event.

Again, the same writer states[c] that in the midst of Babylon a temple, of great height, was built by Semiramis and dedicated to Belus, or Jupiter; and that, on its roof or summit, the Chaldeans contemplated, and exactly noted, the risings and settings of the stars; and we are told by Proclus that the Pyramids of Egypt, which according to the former historian had existed during 3600 years, terminated at the top in a platform on which the priests made their celestial observations. From these relations it would appear that the evidences in favour of both Chaldeans and Egyptians are so nearly equally balanced that it must be impossible to decide between their conflicting claims to the

[a] Isagoge, cap I in Petav. Uranolog.
[b] Biblioth. Hist. Lib. I
[c] Ibid. Lib II

honour of priority, in their application to observative astronomy: when, however, we consider that Asia was the cradle of the human race, and that astronomy, in an equally rude state, was cultivated at the same time in Persia and India as well as in Egypt and Europe, we cannot avoid concluding that the probabilities are in favour of the former people, and that, from the country about Babylon as a centre, the science radiated in every direction with the people who, from thence, colonised the other parts of the ancient world.

Though it seems difficult to imagine that the first men could avoid recognizing the fact that the earth is isolated in space, seeing that the celestial bodies must perform part of their revolutions below the earth, in order to enable them to reappear in the east after having set in the west, yet the accounts collected from the most ancient authors concerning the nature of the universe coincide nearly with each other in representing the earth as a plane figure, bounded on its whole circumference by an ocean of vast extent The description which Homer gives of the Shield of Achilles, near the end of the eighteenth book of the Iliad, is universally supposed to be drawn from the opinion prevalent in his day concerning the form of the earth. The sculpture exhibited in the central part of the shield is evidently intended to represent the various circumstances of human life, and the margin which enclosed the terrestrial scenery was sculptured in imitation of what is designated the Ocean River, it is, therefore, likely enough that the circular disc represented the figure of the earth itself. Herodotus, in his fourth Book, describes the earth as having a form similar to that assigned to it by the Father of poetry; and he adds that geographers so represented it in his time. These opinions seem conformable to what we learn from Diodorus Siculus and Plutarch; the former of whom asserts that the Chaldeans considered the earth to rest on the waters like a boat, und the latter[a] ascribes a like opinion to Heraclitus. It may also be observed that the southern constellations in the great zodiac at Denderah are represented in boats, a circumstance which seems to prove that the ancient Egyptians thought the parts of the earth beyond the regions

[a] De Placitis Philosophorum.

then known, were bounded by an ocean: and the following passage among many similar ones in the Orphic Hymns clearly expresses the same opinion,

Ὠκεανός τε πέριξ ἐνὶ ὕδασι γαῖαν ἑλίσσων [a].

Cleomedes alleges, however, that the notions of the ancients concerning the figure of the earth were various; and that though some considered its surface to be a plane, there were others who would have the mass to be in the form of a cube, a cylinder, or a pyramid [b].

It may be inferred from the language of Homer in the Odyssey that, in his days, the Mediterranean was supposed to be situated in the centre of the earth's disc, and to communicate with the surrounding Ocean River at one extremity [c]. The continent which enclosed this ocean was the abode of the Cimmerians and the Dead, and is described as not enjoying the light of the sun, probably because it was supposed to be at a vast distance from the path of that luminary, this path being imagined to terminate but a little way beyond that region of the earth which constituted the limit of the Phœnician navigation on the western side.

The heavens were conceived to be bounded by a hemispherical and crystalline vault, whose base was on the circumference of the continent beyond the Ocean River just mentioned. a notion also alluded to in the Orphic Poems:

τέρμα φίλον γαίης, ἀρχὴ πόλου, ὑγροκέλευθε [d],

and, within this vault, the sun, moon, and stars were supposed to perform their daily movements In the first book of the Odyssey, the heavens are described as resting on columns, and the mountains at the western extremity of the Mediterranean sea, which were designated the Pillars of Hercules, were, probably, so called in allusion to the opinion that the celestial vault was supported in that manner. But Homer seems to have improved upon the original notion, by supposing a vault to exist below the earth, similar to that above it, this is the Tartarean gulf alluded to in the eighth book of the Iliad, the gloomy abode of the Titans from which the light of the sun was

[a] Hymn XI. (10) ver. 15.
[b] Cleomedes De Mundo, Lib. I
[c] Odyssey, Lib XI.
[d] Hymn LXXXII. ver. 7

supposed to be for ever excluded. The summit of the upper vault is thought to have been the heavenly Olympus; and from hence the gods were supposed to make their occasional visits to the sons of men. According to Diodorus Siculus[a], the upper and lower poles of the vault were the seats of the thirty divinities who superintend the things done above and below the earth.

Ideas resembling those expressed by the heathen poets occur in the Book of Job: where the Deity is described as spreading out the heavens[b]; encompassing the waters with bounds[c]; alluding, perhaps, to the continent beyond the Ocean River, and making the pillars of the earth to tremble[d]. This continent, however, differs from that which, in the Homeric cosmography, is described as the seat of the Cimmerians, and seems to correspond with the Elysian Fields in heathen fable; since, according to Rabbinical tradition, it was the place of the terrestrial paradise and the bright abode of the spirits of good men after death.

It was evidently the opinion of the Eastern sages, in very ancient times, that the surface of the earth is nearly a plane, and that in its central part, which was conceived to be situated northward of the regions then occupied by men, (that is beyond the frontiers of India, Persia, and Greece,) is a very high mountain intercepting the view of the sun during part of his daily revolution, and thus producing the darkness of night: it was believed that the mountain is of a conical form, that according as the sun was more or less elevated above the earth, for it appears that this luminary was supposed to describe about the mountain a spiral curve alternately ascending and descending, he remained concealed during a less or greater portion of time, respectively, and that thus the days and nights were rendered of variable length. The idea bears the marks of an origin which may be dated from a time preceding that of the formation of the opinion that the celestial bodies, in their daily revolutions, pass under the visible surface of the earth; and it seems to be a part of the ancient hypothesis that the earth constitutes the general basis of the universe The circumstances above alluded to are briefly indicated in the *Boundehesch*, a supposed translation of

[a] Bibl. Hist Lib. II. [b] Ch. IX. ver 8. [c] Ch. XXVI ver. 10. [d] Ibid. ver. 11.

one of the works of Zoroaster, where it is said that the mountain Tirch, or Albordi, the Someirah of D'Herbelot, rises in the midst of the earth, that about it the sun revolves daily, and that his movement of ascent is continued during 180 days; when, having gained the top, he remains stationary for a time, and during the following 180 days he descends. the interval between every two arrivals of the sun on the [front of the] mountain constituting one day[a]. The same mountain is, also, said[b] to surround the earth and to reach the heavens; probably signifying that lofty branches from the central mass extended towards the ocean on which the earth seemed to rest, and following its shores, encompassed the terrestrial surface. It is added that the mountain was 800 years in attaining its greatest height; and that, in periods of two hundred years, it reached successively the stars, the moon, the sun, and the region of primitive light. Four seas, or rivers, are said[c], by the beneficence of Ormusd, to flow from the Albordi, in order to water the earth; and M Anquetil supposes the rivers to signify the Indian Ocean, the Persian Gulf, the Caspian and the Mediterranean Seas.

The same ideas occur in the Brahmanical Fables, where we find it stated that Mount Meru, with its three peaks or summits and its seven steps or terraces encompasses the whole earth; that the gods are seated on it, and that, upon one side is the residence of Brahma, the holy city Brahmapuri, from the four gates of which issue as many rivers[d]. The central mountain is, in the *Pauranicas*, described as a column 84000 yogurs high, 16000 broad at bottom, and 32000 at top; consequently, if there is no mistake either in the original or the translation, resembling an inverted cone. and Captain Wilson observes[e] that this may be the figure of the earth alluded to by Cleanthus, Anaximenes, and others, among the western philosophers. The seven steps about Mount Meru resemble the seven earths surrounding Mount Moriah, according to the Rabbinical story related by Basnage in his History of the Jews; and the four

[a] Boundehesch in the Zendavesta, Sect. v [b] Ibid. Sect. xii.

[c] Ibid. Sect xiii.

[d] Asiatic Researches, Vol. X. Essay on the Sacred Isles of the West.

[e] Ibid. Vol. VIII.

rivers mentioned both in the Persian and Hindu Cosmographies may be thought to correspond, in a certain degree, with those which in the Holy Scriptures are said to flow from the Garden of Eden.

It might be expected that, among the ancients, the uncivilised people and those possessing few ideas, should have formed such notions concerning the heavens as correspond rather with the sensations excited by the first view of the most obvious phenomena than with the real nature of the celestial bodies, accordingly we find that there were men who, as Plutarch relates[a], supposed the stars to be extinguished every evening and rekindled in the morning: the same wild fancy is by Achilles Tatius attributed to Xenophanes[b], and we learn from an observation of Cleomedes[c] that the Iberians pretended they could hear, when the sun descended into the ocean, a hissing sound, like that of heated iron when plunged in water.

In modern times we find that, among the natives of the Society Isles in the Pacific Ocean; a people in almost the lowest degree of civilization and completely destitute of any thing that may be called science, notions were entertained which strongly resemble, or rather, are nearly identical with those above mentioned. Mr. Ellis, speaking of their cosmography, says that they imagined the sea which surrounds their group of islands to be a level plane, and that, at the visible horizon, or at some distance beyond it, the sky joined the ocean, enclosing as with a vault the islands in the immediate vicinity: every foreign land they supposed to have a distinct atmosphere and to be enclosed in a similar manner by its particular vault. Some of the natives, Mr Ellis continues, considered the sun as an animated being; and others, that it resembled fire; they imagined that it sunk every evening in the sea, and passed, during the night, by a submarine passage from the West to the East, where it again rose from the sea in the morning, an idea which, also, occurs in the writings of the Greek poets: being asked if they had ever seen the sun descend into the sea, they answered that

[a] De Placitis, Lib II cap. 13.

[b] Tatius, Isagoge ad Phænomena, cap. 5. in Petav. Uranolog.

[c] De Mundo, Lib. II.

they had not, but that some of the people of the western island had heard the hissing occasioned by its plunging into the wate The Tahitians imagined, adds the same author, that, above th earth, there was a series of celestial strata, ten in number, eac of which was the abode of spirits or gods whose elevation wa regulated by their rank or power: the tenth, or last heaver which was enveloped in perfect darkness, being the abode of th first class only[a]. No doubt can therefore exist that suc opinions are those which first suggested themselves to the unen lightened spectator of the heavens, in the infancy of the huma race The more complex cosmogony of the ancients may hav followed next; but this cannot be supposed to have been forme by persons who paid any attention to what they saw of th celestial movements: on the contrary it may apparently wit reason be suspected that the opinions on which that cosmogon is founded, were maintained only by the poets, who may hav invented or adopted them for the sake of the effect they produc in compositions intended to afford pleasure and surprise by th exhibition of whatever is sublime and beautiful, but in whic there is not required a strict attention to what is probable o even natural. Among the ancient Egyptians and Hebrews mor rational ideas seem to have prevailed concerning the mundan system; for Diogenes Laertius[b] relates that the former peopl considered the earth as spherical; and in the book of Job[c] it i said that the north is stretched over the empty space, and tha the earth is suspended from nothing · from which it may b inferred that the earth was then conceived to be isolated fror the rest of the universe.

> Nunc quia non imo tellus dejecta profundo,
> Sed medio suspensa manet, sunt pervia cuncta,
> Qua cadat, et subeat cœlum, rursusque resurgat.[d]

Nor can there be any doubt that the arguments of Cleomede in support of the true figure and situation of the earth were ver early understood. "The heavens, indeed," he says[e], "appea to surround all things about us, and, if we proceed to any othe

[a] Polynesian Researches, Vol III. Chap 6 [b] In Proœmio
[c] Chap XXVI ver. 7. [d] Manilius, Astronomicon, Lib I ver 179
[e] De Mundo, Lib. I

climate, they are still above our heads, nor do they any where rest upon the earth" And again[a], "if the earth were of a plane figure all men would have the same horizon; the rising or setting of the stars would take place at the same time for all; and there would be the same beginning of the day or night"

The globular form of the earth was early known to the Greeks, and we may observe that Herodotus[b] mentions a people who sleep during six months of the year, a circumstance which seems to shew that in the days of that ancient writer men had some knowledge of the periods of light and darkness about the pole of the earth; or that, from a well founded hypothesis concerning its figure, they had arrived at just conclusions respecting the phenomena exhibited on its surface by the apparent revolution of the heavens

When the fact that the earth is entirely detached from all the other parts of the universe was recognized, man, not satisfied with the ample field for research afforded by nature on his own domain, took flight, in imagination, beyond the utmost bounds of the visible heavens, and hesitated not to build up theories regarding subjects which will probably be for ever beyond his comprehension.

The accounts handed to us by Diogenes Laertius, and by Diodorus Siculus concerning the cosmogony of the Egyptians and Chaldeans shew that material substance was considered by these people to be the principle of all things, and that from it, by subdivision, the four elements, fire, air, water, and earth, and all animated beings were produced[c]. This idea is developed by Diodorus, who states[d] that the heavens and earth originally, by the mixture of all substances, existed in a chaotic state, and that after the precipitation of some, the universe assumed the form we behold: the fiery part, on account of its levity, ascended to the upper regions; and, from the same cause, the sun, moon, and stars, which were supposed to be of the

[a] De contemplatione orbium cœlestium, Lib. I. cap. 8.

[b] Melpomene. [c] In Procem.

[d] Bib Hist Lib I. sect. 7.

nature of fire, were placed in the firmament; a notion thus admirably expressed by Manilius:

> Ignis in æthereas volucer se sustulit oras,
> Summaque complexus stellantis culmina cœli,
> Flammarum vallo naturæ mœnia fecit [a].

But the vapours and denser matter were imagined to have subsided together in one place by their weight: the latter constituted the solid part of the earth, and the former, by continual motion disengaging itself, formed the seas and air It is also asserted in the ancient poems entitled the Chaldean Oracles, from an opinion that they contain a summary of the notions in philosophy entertained by the earliest people of Asia, that the universe was divided into seven distinct spaces or worlds; "the Father," it is said in the poem on the heavens, "made seven worlds, including them under a globular form: he made the great host of inerratic stars; he also placed the earth in the centre, the waters within its bosom, and the air above it."[b] The worlds here alluded to are by Psellus, the commentator, considered as concentric spheres, and are thus enumerated. The first, constituting the exterior of the universe, he supposes to be empyreal, or formed of pure elementary fire, within this he imagines that there are three æthereal spheres formed of elements less subtle than the first; the three last are supposed to be what were commonly designated the material worlds, and consisted of the sphere of the fixed stars, the seven planetary spheres and the sublunary region, and Mr. Stanley supposes that in the latter are comprehended the spheres of air, water, and earth

The constitution of the universe was explained in a similar way by Hecateus of Miletus, in a work on the Philosophy of the Egyptians, among whom also the same doctrines appear to have been received [c], and Achilles Tatius observes that the sectators of Orpheus, meaning those who, in his day, adhered to the Chaldean philosophy, compared the three principal divisions

[a] Astronomicon, Lib. I. ver. 495.
[b] Stanley, History of Philosophy. Chaldean Philos
[c] Diog Laert. in Prooem.

of the universe to the shell, the white, and the yolk of an egg [a]. By the elementary fire, supposed to constitute the outer sphere, or the shell of the mundane egg, is to be understood matter, if the word may be allowed, in the highest degree of attenuation, and, as it were, a fire without heat. On the exterior of the universe, says Aristotle [b], no substance can possibly exist.

Whatever might have been the ideas of the first people concerning the nature of the æthereal spheres, we learn that, in later times, their place was, by some, supposed to be occupied by a crystalline substance which enclosed the three material worlds as within a hollow globe. Thus Seneca says [c], "if we may believe Artemidorus, the vault of the heavens is solid and like a roof, and beyond this is the region of fire in this vault are certain apertures like windows by which the external fire enters and becomes incorporated with that about the earth." Seneca justly condemns the notion of Artemidorus, and observes that, to oppose it, would be as useless as beating the air; yet so strong has been the propensity of man to refer every appearance in the heavens to a mechanical cause that, as Macrobius relates [d], a certain Theophrastus who is, moreover, said to have written a history of Astronomy, not only maintained the same opinion, but asserted, besides, that the Via Lactea was the place of junction of the two hemispheres constituting the shell, this junction being supposed to be imperfect, he imagined that the light beyond the sphere was rendered visible through the intervals.

The argument by which the spherical form of the universe was proved by the ancients, is founded on the supposed perfection of a circle, and, consequently, of bodies bounded by that figure. Aristotle, in his treatise *De Cœlo* [e] states, that no right line is perfect because it has terminations, and the inference is, that the perfection of a circle consists in its having none: he observes, also [f], that since that which is perfect must have preceded that which is imperfect, the circle is the first of plane figures and the sphere, the first of solids, therefore, conceiving

[a] Tatius, Isagoge, Cap. 4 in Petav. Uranolog.
[b] De Cœlo, Lib. I. Cap 9.
[c] Nat. Quæst. Lib. VII. Cap. 13.
[d] Comment Somnium Scipionis, Lib. I. Cap. 13.
[e] Lib. I. Cap. 2.
[f] Ibid. Cap. 4.

the universe to have existed from eternity, he concludes that it must be comprehended within a spherical figure. In the ancient schools this mode of reasoning too commonly supplied the place of inductions from facts and observations, even when the circumstances were such as to render facts and observations accessible; and the practice of arguing instead of observing is to be ascribed to an indolent neglect of physical researches, or to the prejudice arising from a habit of recurring to the imagination when physical data were wanting. In either case, we can only consider such reasonings as vain attempts to conceal that ignorance which it would have been more consistent with the spirit of sound philosophy to have acknowledged.

The ancient Greeks seem to have entertained an opinion of the arrangement of the elements constituting the universe, which differs in some respects from that of the Chaldeans or Egyptians. According to the Pythagoreans[a], the grosser materials were situated towards the circumference, and the central part was the region of fire, which was there disposed because it was conceived to be the most noble of the elements, and because the centre was also considered as the most honourable place, but it appears that some parts of the different elements were imagined to be diffused through all space and to enter into the composition of the earth and planets. About the region of fire were conceived to be arranged, in succession, those of air, water, and terrestrial matter, forming so many concentric shells, and in the last the earth was supposed to be placed, beyond the region of the earth came the seven planetary spheres, and the whole system was enclosed within the sphere of the fixed stars.

The idea entertained by the ancient Hindus of the antiquity of the earth, and their doubts concerning the cause and manner of its existence are finely expressed in the tenth chapter of one of the *Vedas*, according to the translation of Mr. Colebrook. "Who knows exactly, and who shall in this world declare whence and why this creation took place? The gods are subsequent to the production of this world; then who can know from whence it proceeded? or whence this varied world arose? or whether it uphold itself or not? He who in the highest

[a] Aristotle De Cœlo, Lib. II.

heaven is the ruler of the universe does indeed know; but not another can possess that knowledge[a].

The opinions of the Hebrews concerning the constitution of the universe, were probably the same as that of the Chaldeans; for, from passages in the sacred Scriptures, it has been inferred that the former people considered the heavens to be three-fold: the lowest was conceived to be the earth, and the surrounding atmosphere, the region of the clouds, the second was the region of the stars; and the third, the abode of the Deity. This last is supposed by the commentators to be that to which St. Paul alluded when he said he was caught up to the third heaven.

It was a general opinion among the ancient philosophers, that the Earth was the most important body in the universe and was, even, the source of the principle of existence in all the others: the air was supposed to be nourished by the humid vapours exhaled from its surface, the ether, by the air, and the stars by the ether, a notion expressed by Lucretius, when he asks,

> "Unde mare, ingenui fontes, æternaque longe
> Flumina suppeditant? Unde æther sidera pascit?"[b]

and maintained by Cleanthes, who, according to Cicero, asserted that the stars are proved to be constituted of fire by the evidence of two senses, the touch and the sight, and that they are consequently fed by the vapours of the ocean. "Nam solis candor illustrior est, quam ullius ignis, quippe qui immenso mundo tam longe lateque collucat: et is ejus tactus est, non ut tepefaciat solum, sed etiam sæpe comburat. quorum neutrum faceret, nisi esset igneus. Ergo, inquit, cum sol igneus sit, oceanique alatur humoribus (quia nullus ignis sine pastu aliquo possit permanere); necesse est, aut ei similis sit igni quem adhibemus ad usum atque ad victum, aut ei qui corporibus animantium continetur"[c]. The opinion that the Earth affords aliment to the stars is also alluded to by Cleomedes[d], who, having remarked that the Earth is but as a point when compared with

[a] Asiatic Researches, Vol. VIII sect. 8.

[b] De Rerum Natura, lib. I ver. 230

[c] De Natura Deorum, lib. II. cap. 15.

[d] De Contemplatione Orbium Cœlestium, lib. I. cap. 11.

the distance of the sun and the celestial sphere, says, we need not doubt that this small earth can supply nourishment to the heavenly bodies, however vast and numerous they may be, since, though small in size, it is great in power and contains almost the whole of existence in itself.

We must not, however, conclude that such opinions were universally held: in fact, those who, like Aristotle, conceived the celestial bodies to be eternal, contended either that they furnished their own aliment, or that none was necessary for them; and Proclus observes that only those bodies which are corruptible can receive increase or suffer diminution; the heavens remain for ever unchanged [a].

The first intimations we have received concerning the practice of observing the heavens will be found in those obscure notices which the Greek writers, of a comparatively late period, have given of the early state of the Chaldeans and Egyptians. It is plain from the passage above quoted [b], in Diodorus Siculus, that, at Babylon, a college of priests must have been instituted by the first sovereigns of that part of Asia for astronomical purposes; that their observatory was on the temple, or at least, on a tower belonging to the temple of the deity to whose service they were consecrated: we learn also, that the tower was quadrangular, probably of a pyramidal form, and was constructed so that its four faces were opposed to the four cardinal points of the horizon. A similar disposition is found to have been given to the faces of the different pyramids in Egypt; and we have shewn that these masses are stated to have been used as observatories: it cannot be doubted, therefore, that such a disposition has been given by design, and we can conceive no other reason for it than to ascertain, by looking along the southern or northern faces, the days when the sun, or any other celestial body, rises and sets in the eastern and western points of the horizon, respectively: or, by looking in a direction parallel to that of the other faces, as in modern practice, to find when the celestial bodies are in the plane of the meridian. Be this as it may, it is evident that, at the time of constructing these works,

[a] Proclus in Timæum, lib III.

[b] Page 24

the two people must have known how to trace a meridian line, and the Egyptian pyramids are still existing monuments of this step in the ancient science: it must be owned, however, that to *orient* a building is not a work of much difficulty, when great precision is not required, since it would be only necessary to mark on the ground a line between the spectator and a terrestrial object when the string of a suspended plummet appears to pass through the pole star and that object.

CHAPTER III.

THE NATURE OF THE EARLIEST OBSERVATIONS.

General phenomena of the heavens.—The phenomena of the sun and moon used as measures of time.—The moon's proper motion, and phases, observed.—Division of the fixed stars into particular groups.—The original constellations changed by the Greeks.—Description of the constellations.—Their designations supposed to relate to the qualities of the seasons.—Astrological notions connected with the constellations.—The sun's proper motion, and the direction of his visible path ascertained.—The use of the gnomon in astronomy.—Methods of obtaining a well defined shadow.—The length of the year determined by the gnomon.

Now if, in the absence of all positive information concerning the first discoveries relating to the movements of the heavenly bodies, of which indeed scarcely a trace has been preserved, we might be permitted to supply the deficiency under the guidance of such hints as can be collected from the ancient writers, we would venture to assert that they must have taken place nearly in the following manner.

A general and circular movement of the bodies in the firmament would be the first phenomenon recognized even by a superficial observer. The shepherd who watched his flock by night on some plain bounded by the horizon would soon perceive that certain stars rose from the ocean, or from behind the hills which limited his view towards the east, and each, after describing a curve in the heavens, disappeared behind the terrestrial objects about the west, that some performed their revolution without descending so low in any part as to reach the horizon; and, finally, that one star seemed to be stationary in the heavens during all the time that the absence of the sun permitted it to be visible; nor could these phenomena fail to suggest the idea of the revolution of some geometrical figure, as a cone, a cylinder, or a sphere, about a certain line passing through the eye of the observer, and situated obliquely to the plane of the terrestrial horizon. How long any doubt existed concerning the true figure of that surface on which the celestial bodies appear to describe their daily revolutions is uncertain.

We have seen in what manner Aristotle argued in favour of the opinion that the universe is globular, and such reasoning may, from the first, have been considered as establishing the belief that the starry heaven was of a like form; but the means explained by Proclus [a], of ascertaining its true figure, have so much the appearance of being those which would present themselves to the minds of the earliest enquirers into the causes of the celestial phenomena, that we cannot do better, in this place, than describe them. This writer first observes that some of the stars evidently describe complete circles daily in the heavens about one fixed point, then, in proof that the movement of the sun is circular, he alleges the inequality in the lengths of the days and nights in different seasons, and the changes gradually made, during the day, in the position of the shadow cast by any terrestrial object; and, lastly, he shews that the sun is, at all seasons, on the surface of one sphere because his apparent magnitude is invariable which, he says, could not be the case if, from midwinter to midsummer, he had moved northwards on the surface of a cylinder or cone, since, in one situation, he would then, evidently, have been nearer to the spectator than in the other, and consequently, he ought to have appeared greater.

However inconclusive this argument may seem to a modern astronomer, whose instruments afford him the means of detecting the periodical variations in the apparent magnitudes of the sun and moon, to the ancients it must have been in the highest degree satisfactory. The planets and fixed stars did not, on account of their smallness, admit of this kind of proof, but the celebrated Euclid [b], by a comparison of the visible magnitudes of the circles they describe about the pole, demonstrated that the revolving surface to which they belong could be no other than that of a sphere. The results, however, of Euclid's demonstration were, in all probability, very early anticipated, for it appears to have been, from the first, generally understood that the celestial bodies were attached to the concave surface of a spherical shell which revolved in a certain time about the

[a] In Timæum, lib. III [b] Phænomena

earth, and that the latter was situated in or near the centre of this concavity.

The phenomena presented by the sun and moon would doubtless next attract the attention of persons impelled to seek information concerning the objects that surround them by that curiosity which, for his improvement, has been so deeply implanted in man. The risings and settings of the former, which afford the means of measuring intervals of time for regulating the ordinary occupations of life, would be immediately attended to, and employed for that purpose; the inequalities of the periods of alternate light and darkness being for some time, perhaps, disregarded.

The remarkable variations in the apparent form of the moon, by recurring constantly in a certain order would, no doubt, be the indices by which the first steps were taken for the division of time into periods exceeding those marked out by the intervals between the sun's rising and setting; and, by the inhabitants of a maritime region, it is probable that those changes would be suspected to have some connexion with the changes in the elevations of the waters on the coast or in the mouths of rivers It is easy to observe that a portion of time equal to that including about thirty repetitions of the sun's risings would be comprehended between two successive appearances of the moon in the crescent form; hence, such a phenomenon would be a convenient signal by which to regulate the celebration of some periodical festival, or the commencement of a journey to some distant place; indeed, we find, among all nations not enlightened by science, that the first appearance of the new moon, as it is called, is made use of for those purposes, and one of the duties of an established priesthood seems, at first, to have been the looking out for, and giving notice of that event. The times at which the moon presents a full round orb being found to occur about the middle of the interval of two of her successive appearances in the crescent form would, also, be made available for the same purposes, and even the various phenomena of the increase and wane might be objects of attention, but the times of their accomplishment being marked less precisely would not, perhaps, be so generally useful The appearances of particular

stars with the sun, either on the same or on opposite sides of the horizon would also, as we have shewn, afford indications of times useful for many of the purposes of human life; but it is probable that these were not attended to till long after the more remarkable phenomena of the sun and moon had been made subservient to those to which they are applicable.

The contemplation of the moon's progress through the heavens would, in a few nights, lead to the discovery of a twofold movement in that luminary, for it could not escape observation that while, like the rest of the heavenly bodies, she moved during the night from east to west, she gradually receded from certain stars and approached others situated towards the east of them by a movement contrary to the former: and, if her position with respect to some remarkable star seen after sunset on any night, was compared with her position with respect to the same star on the following night, it would be found that she had made a movement towards the east, during the intervening time, of more than one thirtieth part of the whole circumference of the celestial sphere. The phenomena consequent upon this movement take place in the following manner, and they must have been so observed from the first moment the heavens were regarded with the least attention.

The moon first becomes visible near the setting sun and then she has the form of a slender crescent of light. At the close of the following day she appears to have receded considerably from the sun towards the east, she sets later and her luminous face is found to have increased in breadth. This deviation from the sun and the augmentation of breadth continue to increase daily and, in less than seven days, she is, at the setting of the sun, distant from that luminary as much as one quarter of the circumference of a circle surrounding the heavens, and her form is that of a semicircle. At the end of about seven days and a half from this time she has receded from the sun to the extent of half the circumference of such a circle, she appears to rise in the east when the sun is setting and her brilliant disc, which had assumed an oval form by gradually increasing in breadth, becomes an entire circle, in which state she is designated the

full moon. From day to day after this time, she appears to approach nearer the sun on the eastern side, her disc diminishes in breadth so that she again assumes an oval form, and, in about seven days and a half from the time of her appearance as a full moon, she is once more reduced to a semicircle. In less than seven days afterward her disc, which had daily become more slender, appears but as a thread of silvery light in a crescent form; she then appears to have nearly returned to conjunction with the sun and she rises in the east but a short time before him. Then, after remaining for a few days invisible, as if lost in the superior brilliancy of the orb of day, she again appears in the form of a fine crescent of light near the setting sun, as at first, and all the above phenomena are repeated in the same order as before. Such phenomena must have been observed long before the oldest works on astronomy, now extant, were composed; for, in them, we find allusions made to, and inferences drawn from, such phenomena as if they were familiarly known; and it was, probably, as anciently suspected that the moon, during the interval between her disappearance when lost in the rays of the morning sun and her reappearance on emerging from those of the evening sun, accompanied, though invisible, the great luminary during his daily progress through the heavens.

These phases would naturally give rise to the desire of finding the cause which produced them, and the opinion was probably soon formed that they had some dependence on the position of the moon with respect to the sun; but as it was not till after some progress had been made in the study of astronomy that the notions first entertained of that cause were developed in such works as have reached our times, it will be proper that the consideration of them should, for the present, be deferred.

But the convenience of referring the moon to some particular places in the heavens would render it necessary to preserve a knowledge of the configurations of the groups of stars which lie near her path, and steps would early be taken to recognize those groups by some distinguishing marks. The most simple idea would be that of assigning them a fancied resemblance to the figure of a man or animal; and a lively imagination would as

easily trace such resemblances among the stars as a mind not otherwise occupied traces them in a fire, or in the clouds which spread their various forms across the summer sky.

It is probable that, at an early period, an effort was made to determine the positions of stars with more precision than could be obtained by a mere reference to some part of the body of the figure to which the group containing them had been reduced; and a method similar to that employed by Ferguson, in the last century, may have been practised nearly five thousand years since by the inhabitants of the Assyrian plains, whose science was, perhaps, about equal to that of the self-taught Scottish peasant. We can conceive that a primitive star-gazer might hold before his eye a frame across which were extended three slender threads intersecting each other so as to form a triangle whose sides could be made of various lengths by changing the positions of the threads; the intersections, being made to coincide with the apparent places of any three stars, would give, on transferring the triangle to a plane surface, the relative situations of the stars; from which those of other stars might be found in the same manner till a whole group or, even, the stars contained in a narrow zone of the heavens were represented, and there can be little doubt that, by such a process, simple planispheres were formed long before the theory of projections was discovered. By constructing such representations of portions of the starry sphere on a plane, or on the surface of a ball, it is evident that the determination of the paths and movements of the sun, moon, and planets would be greatly facilitated, for this purpose, with respect to the moon and planets, it would be only necessary to extend a thread to pass through the apparent places of those bodies and some of the neighbouring stars, in two different directions, then lines being drawn on the planisphere, or arcs on the surface of the ball, to pass through the representations of the stars, the intersection would give the place of the moon or planet.

The figures under which the stars have been grouped, originally, perhaps, represented the deities of the East, and some of the principal circumstances connected with husbandry and reli-

gion; and it was probably as much for the purpose of transmitting those circumstances to posterity as of facilitating a knowledge of the places of the stars, that such figures were imagined to exist on the surface of the celestial vault. But when the science of astronomy began to be cultivated by the Greeks, the vanity which prompted this people to ascribe to persons of their own nation the achievements of foreign heroes, seems to have led them even to change the legends pictured by the Chaldeans and Egyptians on the face of heaven for others drawn from the fables which formed the basis of their own mythology and history. The Mithraic Lion, the symbol by which the earliest Eastern nations represented royalty, is, perhaps, the only constellation remaining of those which were formed by the Chaldeans; and we have the testimony of Plutarch to prove that some, at least, of the actually existing figures are transformations of others which had been placed in the heavens by the Egyptians; for this writer, who, in his treatise De Iside et Osiride, makes the priests of Egypt say that the souls of the gods shine in the heavens and are stars, adds that the constellation of Isis is called, by the Greeks, Canis; that of Horus, Orion, and that of Typhon, Ursa.

The sculptured planisphere which has been recently discovered on the ceiling of the Temple at Denderah cannot be expected to show many of the constellations invented by the ancient people either of Chaldea or Egypt, since its execution is now well known to have been subsequent to the time when the Greek astronomy was prevalent in the East, yet as certain differences are found between the figures on the Egyptian temple and those which distinguish the constellations described by the Greek writers, it is probable that there may be some among them belonging to that distribution of the stars which was made by the people of the country. The above-mentioned assertions of Plutarch seem also to be confirmed by this monument, for in the place of Canis Major is traced a cow, the animal consecrated to Isis; instead of Orion is the figure of a man which is supposed to be intended for the son of Osiris, and in the part where we now place Draco is a figure having some resemblance to that

of a hippopotamus, which, as well as the bear, is said by Plutarch [a] to be the emblem of Typhon and the habitation of his spirit. Near the group of stars representing, as it is thought, the Hyades, is the figure of a hog, which, perhaps, originally designated that cluster, the hog being an animal of great importance to the Egyptians, and from its Greek name, the word Hyades is supposed to have been derived. In the sculpture, the figure of a man with the head of an ox is believed to be the original of the herdsman Bootes, and the place of Ursa Minor is occupied by a wolf.

It is remarkable that the constellation entitled Libra, which is found in all the zodiacs on the Egyptian temples, and certainly formed one of the divisions of the celestial sphere in the ancient Egyptian astronomy, should, from the time of Empedocles [b], have been omitted in the descriptions of the heavens given by the astronomers of Greece, who made the claws of Scorpio extend so far as to occupy all the space which, previously, had been assigned to Libra: the latter was restored by the philosophers of the Alexandrian school, and it has ever since retained its place among the zodiacal signs.

Above and below the twelve zodiacal constellations in the planisphere of Denderah are many representations of men, women, plants, and instruments besides the above-mentioned objects, and M. Jollois endeavours to prove that some of these also represent the constellations which we find upon our common globes [c]. Be that as it may, the ascertained points of resemblance between the figures on the planisphere and those we now suppose to be traced in the heavens, shew that little change has been made in the distribution of the stars since the origin of the Greek astronomy; and, on this account, the contemplation of the figures into which the stars are grouped must possess considerable interest for the classical scholar to whose mind they present an eternal picture of the principal circumstances in the ancient mythology, on which he has from youth been accustomed to dwell with particular delight.

At the time when the stars were first reduced under determi-

[a] De Iside et Osiride [b] Fabricius, Biblioth. Græca, lib. II. cap. 12.

[c] Recherches sur les bas-reliefs astronomiques des Egyptiens, sect. I. ch. 1.

nate figures; that is when the inhabitants of the Assyrian plains made their first observations of the heavens, the space now distinguished by the constellation Draco was immediately in the vicinity of the northern extremity of the axis about which the whole celestial sphere seems to revolve; and one of the stars, since designated α, in that constellation was then so near the pole that it must have appeared stationary during the whole revolution, though now, after a lapse of nearly four thousand years, it has, by that slow movement to which all the stars appear subject, deviated from the pole as much as about 25 degrees. The figure which was, no doubt by the Greeks, made to coincide with a number of stars situated in this part of the heavens, in a curvilinear direction, is supposed to represent the dragon appointed to watch the Garden of the Hesperides. Within one of the sinuosities formed by this figure is placed the constellation Ursa Minor, which seems to have been intended to commemorate the transformation of Arcas, the son of the nymph Calisto, and the grandson of Lycaon king of Arcadia; it consists of seven principal stars, one of which, forming the extremity of the animal's tail, is, at present, the polar star, being situated within two degrees of the point in which the produced axis of the earth would actually meet the heavens. On the opposite side of Draco is the constellation Ursa Major, which represents Calisto herself, it contains seven brilliant stars disposed in a figure resembling that of Ursa Minor, and has been particularly distinguished since the most ancient times, though it did not always occupy the whole of the space at present assigned to it; for the body of the animal appears to have been originally confined, by the Greeks, to the quadrangle formed by the four principal stars

At an equal distance from the place of the present pole of the world, but on the opposite side of it, are situated the constellations Cepheus and Cassiopeia; representing a prince of India or Arabia and his consort: the former contains three distinguishable stars forming an obtuse triangle, and the other contains seven which are so disposed as nearly to resemble the groups composing Ursa Major and Minor. Beyond Cassiopeia towards the south is the constellation Andromeda which may be easily

recognized by its three principal stars lying nearly in a right line and equally distant from each other: this princess was the daughter of Cepheus and is said to have been exposed on the sea-shore by her father, to be devoured by a monster, in order to propitiate Neptune who, for the punishment of Cassiopeia, had afflicted the country with a pestilence. The great constellation Cetus, which is far beyond Andromeda towards the south, is intended to represent this monster; it contains several considerable stars but they are not disposed in any figure which can be easily recognized.

Immediately on the eastern side of Andromeda is Perseus, her deliverer and, subsequently, her husband, who may be distinguished by three considerable stars disposed in a right line, and by two others in a line oblique to the former: near this constellation is a cluster of stars considered as forming the head of the Gorgon Medusa. About the same distance from the present place of the north pole, and on the east of Perseus is the constellation Auriga which is supposed to commemorate Erichthonius king of Athens; it contains but two considerable stars and the greatest of these is situated in the figure of a goat which is borne on the left shoulder of the king and was intended to designate Amaltheus, the nurse of Jupiter.

A long tract extending about the pole eastward from Perseus was occupied, in the ancient representations of the heavens, by stars not formed into any constellation; but beyond Ursa Major came Bootes, or the Pastor, supposed to be Icarus, a king of Lacedemonia who taught the art of cultivating the vine; within the figure are eight considerable stars, but the principal is Arcturus, which is situated in one of his knees. On the eastern side of this constellation is the northern crown which is pretended to be the diadem of Ariadne and consists of several stars disposed in a semicircular order. Continuing in the same direction about the pole we come to Hercules who, anciently, bore in his hand a branch supposed to have been taken from the Garden of the Hesperides, and who is easily distinguished by four stars forming the figure of a trapezoid: then follow the Lyre of Apollo or of Orpheus in which is the brilliant star Vega, and the Swan, supposed to represent Orpheus himself, which is

distinguishable by the principal stars being disposed in the form of a crucifix.

Southward of Hercules is the constellation Ophiuchus which commemorates Esculapius the father of medicine; and several stars forming a long waving line running through the figure are considered as constituting a serpent, the emblem of his wisdom. Near Ophiuchus is the eagle which conveyed Ganymede to the court of Jupiter; it is distinguished by three stars disposed in a right line: a small cluster of stars forming a kind of lozenge represents the dolphin which bore Arion to the shore, and, to complete this circle of constellations, we have Pegasus which sprang from the fountain Hippocrene, the four principal stars in this group being disposed at the angular points of a square in the heavens permit it to be easily distinguished

Twelve remarkable constellations are situated nearly in the direction of the ecliptic and, consequently, serve to mark the places of the sun, moon, and planets, of which all that were known to the ancients appear to describe paths lying within a narrow zone surrounding that part of the heavens. The first of these constellations, which is distinguished by the name of Aries, comes between Andromeda and Perseus but is further towards the south than either, it is distinguished by three stars of different degrees of splendour, which form an obtuse angled triangle, and it designates, probably, the ram bearing the golden fleece which gave rise to the voyage of the Argonauts. Following Aries, towards the east, is the constellation Taurus, supposed to be the bull which carried away Europa; in the neck of the animal is a cluster well known by the name of the Pleiades, and supposed to be the seven daughters of Atlas; and in his head is the very brilliant star Aldebaran and a cluster denominated the Hyades. More eastward is the constellation Gemini representing Castor and Pollux or, according to Hipparchus, Apollo and Hercules; a bright star is in the head of each of these two figures, and below them are four others forming a quadrangle. Next to these follows Cancer, which is supposed to represent the animal sent by Jupiter to arrest the flight of a nymph of whom he was in pursuit; and afterwards, the Nemean lion which was slain by Hercules; this constellation is distinguished

by four stars forming with each other an irregular quadrangle, in the body, and by several others in the head, of the figure. Virgo is the next in order, and represents Ceres or Isis or, perhaps, Erigone the daughter of Icarus; it contains six considerable stars near the western, and one still more brilliant, towards the eastern extremity.

In the more ancient representations of the heavens, the succeeding constellation was Libra, or the Balance, and the instrument was sometimes accompanied by the figure of a man who is supposed to have been its inventor. Scorpio, whose claws, in some of the descriptions of the zodiac given by the Greeks, extended, as we have said, so far as to fill the space occupied, before, and subsequently to their times, by Libra, represents the animal sent by Diana to destroy Orion for presuming to rival her in the chace; the constellation contains several bright stars, of which those at the western extremity are disposed nearly in the form of an anchor. Sagittarius follows, and is considered as commemorating the Centaur Chiron, the inventor of medicine; it is chiefly distinguishable by four stars forming a long quadrangle in the front of the figure.

Capricornus is supposed to designate Pan who took this form in order to escape the giant Typhon: the constellation may be known by two bright stars in the head of the goat and one at the opposite extremity. Aquarius may have been intended to represent Deucalion who re-peopled the earth after the Thessalian deluge, its three principal stars have the figure of a long triangle The constellation Pisces was placed in the firmament to commemorate the transformation of Venus into a fish when, being alarmed by Typhon, she plunged into the Euphrates.

Between Taurus and Gemini, but to the south of both, is the celebrated hunter Orion, who forms the most splendid constellation in the heavens, where, as some suppose, the figure has in every sphere kept unchanged, except in name, the station to which the devotion or the fears of the Chaldeans had elevated their monarch Belus, he is distinguishable by a bright star in each shoulder and leg forming, together, a large quadrangle within which are three stars disposed in a line and resembling a girdle Below Orion, towards the south-east is Canis Major,

originally, perhaps, representing the Egyptian god Anubis but subsequently, by the Greeks, converted into one of the dogs of Orion; in the lower part of the figure are four bright stars and in the upper part, three; one of which (Sirius) is the most brilliant in the heavens. A long constellation to the south of Leo and Virgo represents the hydra of Lerna; and still further southward is the celebrated ship of Argos or, as it is called by Plutarch, the ship of Osiris, in the lower part of which is the bright star Canopus. Between Orion and Cetus, and extending from thence to the South Pole is Eridanus, which is said to represent either the Po, in Italy, or the Nile, in Egypt. And to terminate this brief description of the ancient constellations we may mention the Galaxy, an irregular zone of whitish light which surrounds the heavens, it begins to be visible in the south near the tail of Scorpio where it divides into two branches nearly parallel to each other, passes northward through Sagittarius, Aquila, Cygnus, Cepheus and Cassiopeia; from thence, turning towards the south, it runs through Perseus, Auriga, the feet of Gemini, Canis Major and the ship of Argos, where it ceases to be visible to the inhabitants of the northern regions of the earth. The opinions of the ancients concerning the nature of the Galaxy can hardly be distinguished through the veil of allegory with which they usually enclosed their descriptions of the heavens: on the supposition that the sphere surrounding the region of the fixed stars was a material substance, Œnopides of Chios described this zone as the trace of an ancient road on which the sun once performed his yearly revolutions about the earth[a], and Theophrastus, as we have said, considered it as the place of junction of the two portions which constitute the celestial sphere. Neither of these fancies can be understood as any thing more than a poetical figure; but the writer last quoted has recorded the assertion of Democritus, so remarkably verified by the discoveries of Sir William Herschell, that the appearance is caused by the blended light of an incalculable number of stars situated in that particular region[b]. "*Innumeras stellas, brevesque omnes, quæ spisso tractu in unum coactæ, spatiis,*

[a] Achilles Tatius, Isagoge, in Petav. cap. 24.

[b] Macrob. comment. in Somn. Scip. Lib. I. cap. 15.

quæ angustissima interjacent, opertis vicinæ sibi undique, et ideo passim diffusæ lucis aspergine continuum juncti luminis corpus ostendunt." A similar opinion appears to have been entertained by the ancient Persians.

The account we have given of the zodiacal constellations is in accordance with the notions of those who imagine that they were intended to represent some of the circumstances connected with the Greek mythology; but it is equally probable that the figures have some relation to the rural operations of the ancients, or to the phenomena presented by the sun. It has been supposed that the figure of a ram was given to the assemblage of stars forming the first constellation because, when this division of the heavens was made, the sun was in that part of the zodiac at the season in which animals of the above kind were taken from the stables to the fields. It is also pretended that the lion, an animal distinguished for strength and ferocity, was chosen to represent the violence of the heat experienced in summer, the scorpion, to designate the unhealthiness of the autumn; and the balance, to express the equality in the lengths of the days and nights at the same season The name of Cancer, an animal which is said to move backwards in walking, may have been applied to the fourth constellation to express the return of the sun from the summer solstice, and the name of Capricornus, an animal which seems to have a facility in climbing up rocks, to the tenth, in order to represent the rising of the sun from the winter-tropic. It is worthy of remark that, according to Macrobius [a], the ancients designated the signs Cancer and Capricorn as the gates of the sun, at which, having arrived, that luminary seemed to retrace his path in the zone which he never leaves. Through Cancer, also, he says, the spirits of men were supposed to pass in descending from heaven to earth; and through Capricorn, which therefore was called the gate of the gods, they ascended from earth to heaven.

A probable opinion is expressed in the works of Macrobius and Solinus [b] for the choice of the constellation Aries to mark the commencement of the zodiac: these writers observe that

[a] Macrob. comment. in Somn. Scip. Lib. I cap 15.

[b] Solinus, Polyhistor. cap. 45.

the presence of the sun in Leo, being contemporary with the summer season, in which all the productive powers of nature are displayed on the earth, was, on that account, imagined by the Egyptian priests to coincide with the birth, as it is called, of the universe, but, at the rising of this constellation, Aries is in the mid-heaven, the vertex or summit, as it were, of the celestial sphere, and was therefore appropriately considered as the head or leader of the zodiacal constellations

The particular denominations assigned by the Egyptians and Greeks to some of the groups of stars have been found to prevail among the uncivilised natives of the western world. M. Bailly [a], quoting the words of Pere Laffiteau, states that the Iroquois express the constellation Ursa Major by a word signifying a Bear, he shews also, from Pere Souciet, that the people inhabiting the banks of the Amazon call the Hyades (in Taurus) by a name signifying the jaw of an ox, and, from various authors, that the Galaxy is, by the Greeks, the Arabs, and the savages of America, designated a road, the Chinese, alone, call it the celestial river. The coincidences above mentioned may be accidental, but it is not impossible that some notions respecting the astronomy of the ancient world may have been conveyed across the Pacific Ocean by the Malayan or Mongolian tribes which, with great reason, are believed to have colonised, and for ages possessed the vast continent first made known to the rest of mankind by the genius and fortune of Columbus.

As we purpose to exhibit a view of the progress made in the contemplation of the celestial bodies and their movements, it will not be thought irrelevant to the subject if we here notice the leading phenomena which were supposed to be the proximate causes of the influence of the heavens upon the lives of men, for we consider a knowledge of the human mind to be imperfectly attained unless its aberrations from, as well as its direct advances in the path of science have been attentively studied.

Those who have explained the rules for forming astrological judgments respecting the concerns of men, according to the

[a] Astronom Ancienne Eclairciss. liv. IX sec 1.

principles which they pretend to have been laid down by the Chaldeans, assert that the zodiacal constellations or signs are those which produce the most important effects; that the sign which appears ascending above the horizon at the moment of the birth of a man, determines his character, profession and fortune, and that these are supposed to depend on the qualities or uses of the animal which marks the ascending sign [a]. The extra-zodiacal signs were also supposed to have influences of the same kind, and these were determined in like manner by their ascent above the horizon at the birth [b]. The zodiac was divided into twelve stations or mansions, and that occupied by the moon at the time of the birth of a man determined the duration of his life, the number of years being different in the several mansions [c]. The twelve zodiacal constellations were distinguished into such as were friendly and unfriendly; and persons born under those of the former class were supposed to live together in peace, while those born under the latter were imagined to be inclined to hostility [d] The same constellations were also distinguished according to their *aspects*, which were determined by their angular distances from each other, and denominated *trine*, *quartile* and *sextile*, according as the distances were one-third, one-fourth, or one-sixth of the circumference of the zodiac; the conjunctions and oppositions were also considered as positions of considerable importance. By inscribing an equilateral triangle in the circle of the zodiac, having its angular points in the middle of three of the signs, a trigon was formed, and it is evident that there might be thus formed four different trigons whose angles would fall in all the twelve signs. To these trigons were given the names and qualities of the four elements: thus the first, formed by Aries, Leo, and Sagittarius, was called the trigon of fire; the second, formed by Taurus, Virgo, and Capricornus, was called the trigon of earth, the third, formed by Gemini, Libra, and Aquarius, was the trigon of air; and the fourth, formed by Cancer, Scorpio, and Pisces, was the trigon of water. In like manner there might be formed three tetragons

[a] Astronomicon, Lib. IV ver. 122, etc. [b] Ibid. Lib. V ver 39

[c] Ibid. Lib. III. ver. 568. [d] Ibid. Lib. II. ver. 561.

and two hexagons [a]. It would be loss of time to do more than name these frivolities, we are astonished that they should ever have been the subject of serious consideration for a moment, and it is humiliating to reflect that they once entered into the creed of the learned, in Europe.

The importance of the sun in serving as a measure of time more extensive than that afforded by the moon, must have become sensible when it was discovered that this luminary had a movement from west to east, as well as the latter, though with less apparent velocity, while it also partook of the general movement of the firmament from east to west: and though the observations of that motion could not be so easily made as in the former case because, while the sun is above the circle that bounds our view of the earth and heavens, the stars by which his movement is to be ascertained are rendered invisible from his own superior brilliancy, nevertheless, an attentive consideration of the heavens a little before the rising and after the setting of the sun would soon shew the reality of this twofold movement. In order to detect the motion from west to east, it would be only necessary to take notice of some principal star, which, on any day, ascends above the horizon in or near the east, a short time before the sun, and to repeat the observation after an interval of a few days: it will, then, be apparent that the distance between the sun and that star has increased, so that the latter now ascends above the horizon a considerable time before the sun. Either, then, the star has receded from the sun towards the west, or the latter has advanced towards the east during that time; but, as the relative distances of the stars do not appear to change, it would seem more probable that the observed motion was that of the sun. And if the stars which set soon after the sun were, on any night, observed, it would be found, that, after a few nights, those stars would cease to be visible at sun-set, and others which, before, were situated more eastward than the former would occupy their places near the horizon; a circumstance which also indicates a movement of the sun from west to east.

[a] Astronomicon, Lib. II. ver 270

It is conceivable that such observations would, in the infancy of astronomy, be continued during long periods; and perhaps it would be found that, at the end of a certain time, suppose equal to the interval between two successive summers or winters, the sun, having continued to advance towards the east, had arrived nearly in the same position as at first with respect to one fixed star; and, thus, the length of the year might be found to depend upon a complete apparent revolution of the sun, in that manner, about the earth. Such observations of the rising and setting of particular stars, near the sun, if continued during that time, would also serve to shew, with accuracy sufficient for the purposes of the first observers, the direction of the ecliptic; that is, of the sun's path in the heavens: thus it would be found that this route lay between the stars now marked α in the constellations Aries and Cetus: between Aldebaran and the Pleiades in the constellation Taurus, and so on, through the whole circuit.

The want of precision in the observations of the heliacal risings and settings of stars, as those above alluded to were designated, would, however, afford a determination of the length of the year too vague to be satisfactory even to a people but a little way advanced in the knowledge of the heavens; and the observation of another movement in the sun would lead to a means of fixing its duration within more useful limits It is evident, to the most superficial observer, that the sun, when in the middle of his diurnal course, is more elevated above the southern part of the horizon in one season than in another; and the changes of elevation may be observed to produce corresponding variations in the lengths of the shadows cast by terrestrial objects on the level surface of the ground. Hence would, naturally, originate the idea of raising a gnomon or pillar, in a vertical position, from a pavement rendered as horizontal as possible; that, by the variable length of the shadow, might be indicated the changes in the altitude of the sun, the direction of his path in the heavens, the length of the year, and the division of the day into portions.

The employment of a vertical pillar or gnomon for astronomical purposes, was probably general wherever the science was

cultivated not only in its infancy, but even for some time after graduated instruments had been constructed. Its invention may be ascribed to the Chaldeans, for Herodotus states [a] that the Greeks learned from them (the use of) the pole (πόλον) and gnomon (γνώμονα), and to divide the day into twelve parts; yet it is right to observe that Delambre conceives the terms to signify only the *hemisphere* or sun-dial of Berosus [b]. Be that as it may, we find the gnomon in use among the Greeks and Romans, the Hindus and Chinese; and though no direct evidence now exists that the Chaldeans or Egyptians applied it to the purpose of finding the days of the greatest and least altitudes of the sun, yet it can scarcely be doubted that so simple a means of determining the length of the year must have presented itself to an agricultural people, to whom a knowledge of the returns of the seasons was of the highest importance. The pyramidal stone 130 feet long and 25 feet square at the base, which is said by Diodorus Siculus [c] to have been, by order of Semiramis, hewn out of the mountains of Armenia, and set up in a conspicuous part of the city of Babylon, is, by Maurice [d] supposed to have been the prototype of all succeeding obelisks, and used as a gnomon: and if any dependence can be placed on the assertions of Josephus, it will be evident that in Egypt, from a very early time, the gnomon was in use as a sun-dial to shew the hours of the day; for, in his reply to Apion [e] he makes the latter say, that Moses was of Heliopolis, a city consecrated to the sun; that he was skilled in the learning of the country, and that he had erected a column having, at the top, the figure of a man whose shadow moved with the sun; and it is nearly certain that the dial of Ahaz alluded to in the Scriptures was an instrument of a like nature. The fact that the gnomon was used to divide the day, may be considered as a sufficient proof that, in the same part of the world, it was, also, made to serve for the above mentioned purpose.

The obelisks constructed in Asia, and near the entrances of the Egyptian temples have also, by some persons, been

[a] Euterpe, Cap. 109. [b] Histoire de l'Astron. Tom. I. Additions.

[c] Bibl. Hist. Lib. II. Cap. 1. [d] Appendix to the Ruins of Babylon. [e] Lib. II.

considered as gnomons intended for one or both of these objects, and the opinion seems not destitute of probability, for Pliny observes[a] that obelisks were so called because they resemble the form of the solar beams, and that they were erected among every people distinguished by the worship of the sun, to whom they are believed to have been dedicated; on this account they might, very appropriately, be made subservient to the determination of time. Delambre's objection that the forms of their summits are such as not to permit the extremity of the shadow to be accurately defined does not appear to be well founded, since, at the time of their construction, or while the practice of using them subsisted, there might have been adapted to the upper part of the obelisk, in order to gain the end, a metallic rod, terminating in a point, or a small globe; and we are informed by Pliny that a ball was actually placed upon the obelisk erected by Manlius in the Campus Martius at Rome for the very purpose: or, lastly, as in later times, a perforated plate might have crowned the summit, by which a distinct image of the sun would be formed on the horizontal pavement; and thus, the hour might be shewn, or the time of the solstice ascertained with as much precision as was then required. According to Pliny, the Alexandrian obelisk, now denominated Cleopatra's Needle, was erected by Mesphres, who is supposed to have lived about 1700 years before Christ.

On contemplating the daily state of the shadow cast by the gnomon at noon, an attentive observer would remark that about midwinter it remained, for a few days, apparently of one and the same length; he would afterwards find that it began to diminish, at first by small decrements, but the daily differences of length would soon become more perceptible, and it would be seen that these differences were the greatest at the commencement of the spring quarter of the year. The absolute length of the shadow continuing to decrease, the daily decrements would subsequently be found to diminish in an order exactly the reverse of that which they followed in the previous quarter, and they would become insensible about midsummer when it would seem as if the altitude of the sun at noon remained the same for

[a] Nat. Hist. Lib XXXVI. cap. 8.

a few days; and, hence, would arise the denominations of the summer and winter solstices, which have been applied to the points of the heavens occupied by the sun on the days of midsummer and midwinter. The daily lengths of the shadows would increase from midsummer to midwinter in precisely the same order as that in which the diminutions took place; and a few repetitions of the observations of the days when the shadow was the longest and the shortest would, probably, suffice to enable the ancient astronomers to assign three hundred and sixty-five days to the length of the year, or period between two successive arrivals of the sun at the same solstice. The difficulty of ascertaining the precise days on which the shadow was the greatest and least would, no doubt, be immediately felt, but a mean of several observed times must have given the length of the year correctly, with respect to the number of complete days, and greater accuracy was probably for a long time disregarded. The near coincidence of the day of midsummer, or of the least shadow of the gnomon, with the first appearance of a rise in the waters of the Nile, on which the fertility of the soil of Egypt depends, appears to have induced the people of that country to consider the epoch of the summer solstice as the commencement of one of the parts into which they divided their agricultural year.

The movements of the moon in the heavens would be found to resemble those of the sun, for she has, as we have already mentioned, one motion from the west towards the east, and another, in common with all the celestial bodies, in the contrary direction; again, she attains on different nights, different elevations above the horizon, when in the middle of her nocturnal course; and it must have been soon observed that, within a period equal to, but not always coincident with that which elapses between one change and the following, her elevation varies by a gradual increase from the least to the greatest, and then decreases as gradually to the least.

CHAPTER IV.

THE PRINCIPAL PHENOMENA OF THE SUN, MOON AND PLANETS.

The planets distinguished from the fixed stars.—Their names and symbols.—The visible movements of the inferior planets.—Observed periods of their deviation from the sun.—The superior planets are alternately in conjunction with, and in opposition to the sun.—Observed sidereal movements of the planets.—Possibility that the modern planetary systems may have been imagined by the ancients.—The phenomena of eclipses observed.—Effects of eclipses on the minds of men.—The cause of solar eclipses early known.—Uncertainty of the ancients respecting the cause of lunar eclipses.—The most ancient eclipses recorded.—Probable nature of the early observations of eclipses.—The apparent paths of the moon and planets, and the situation of the moon's apsides recognised.—The comets were noticed by the Chaldeans.

THE practice of observing the heavens frequently in Egypt and Syria, countries which, as Plato observes in the dialogue Epinomis, enjoy, almost constantly, a serene and cloudless atmosphere, would in time permit the spectator to perceive that all the stars do not retain their relative distances unaltered: some of the principal stars would appear to be endowed with movements which resemble those of the sun and moon; for while they partake of the general motion of the celestial sphere from east to west they, at certain times, proceed with a different motion in the same, at other times in a contrary direction; and, again, at various times, when in the middle of their nocturnal course, they may be seen differently elevated above the horizon: lastly, there are certain periods when, for some days, they appear stationary in the heavens with relation to the other stars, though still partaking of the general motion from east to west. It might further be observed that two of these wandering stars, or planets as they were called, had this peculiarity, that they were never seen beyond a certain angular distance from the sun: one of them, to which the name of Mercury was given, would be visible only when near that luminary and for a short time after his setting or before his rising: the other, which was dis-

tinguished by the name of Venus, would exhibit similar phenomena, but would deviate further from the sun than Mercury; it would, consequently, rise at an earlier, or continue visible in the west to a later hour.

The other planets, Mars, Jupiter and Saturn which, as well as those last mentioned, were known from the earliest period of astronomical history, would appear to have greater ranges of motion, being sometimes seen near the sun and sometimes at a distance from him equal to the whole diameter of the visible heavens, for they would frequently be seen rising in the east when that luminary was setting, or setting when he was rising. Jupiter and Venus from their superior brilliancy, which permits them to be visible when in the vicinity of the sun, were early distinguished by the epithets of Lucifer and Hesperus, and received the denomination of morning or evening stars according as they were seen with the sun at his rising or setting.

The names of the planets may have been given from some resemblance imagined to exist between them and the attributes of the deities worshipped in the heathen world, thus one planet, from its swift motion and vicinity to the sun, received the name of the Messenger of the Gods; another, from the brilliancy of its light was denominated Venus, and a third, from its fiery aspect received the appellation of the God of War, and so on While the reveries of a degrading superstition prevailed among men, a child which happened to be born at the time of the rising of any particular planet was considered as under the protection of the deity whose name it bore, and his disposition was supposed to resemble that of his patron-god The Jewish and Arabian writers of the middle ages inform us that the Chaldeans gave to each planet a certain symbol denoting its quality, as a hexagon to Saturn, a triangle to Jupiter, a square to the sun, and the like, and the symbol of the Deity, the First Cause, or the Eternal Mind was a circle which, as we know from other authorities, was considered as the most perfect figure. We are informed also that fire, or the sun, was considered as a symbol of the First Cause, and that all these symbols were worshipped as representations of their prototypes: and we learn from the same

writers that the Chaldeans divided the heavens into what were called mansions; assigning to each planet a mansion and the care of some species of beings on the earth.

According to Plutarch[a], Pythagoras ascribed the figures of what are called the regular bodies to the four elements and the universe, thus he is said to have made the cube represent the earth, the pyramid, fire; the octahedron, air; the icosahedron, water, and the dodecahedron, the whole of nature M. Bailly[b] supposes these symbols to have originated in the idea that material substances are formed by crystallisation and that the regular bodies have, respectively, the forms of the primitive crystals in each of the elements; but it is more probable that the symbols, like those applied by the Chaldeans to the planets, were intended to represent the comparative excellences of the different elements themselves. The opinion of a divine agency in the stars, which was, first, attributed to them by the Chaldeans, probably spread from the country occupied by this people, as a centre, into other parts of the East, and to Egypt; from whence it was, in time, conveyed to Europe, where, during the long period which preceded the birth of the modern philosophy, it almost universally prevailed.

There cannot be a doubt that the movements of the planets, as far as they could be ascertained by the unassisted eye were, from the first, attentively studied, but since the variations of their apparent forms could not, without the aid of telescopes, be distinguished, the principal fact on which a knowledge of the nature of their real movements depends was wanting; therefore if the ancients ever possessed that knowledge we are certain that they must have attained it by conjecture only. Yet enough could be observed, to have led them to the formation of an hypothesis concerning those motions similar to that which is now universally admitted; and sundry passages in the works of ancient authors have been adduced to prove that such an hypothesis had not escaped the ingenuity of the Egyptian and Greek philosophers. Whether this were the case or not will be for ever uncertain, but to enable us to form a judgment of its possibility

[a] De Placitis, Lib II Cap. 2. [b] Astron. Ancienne.

it will be necessary to shew what were the phenomena which might have been observed before any instrument was invented, and before any means were in use for measuring time except those afforded by the succession of days and nights.

Perhaps the most striking phenomena of the planetary motions would be the limited deviations of Mercury and Venus from the sun; repeated observations must have shewn that, from the respective times at which they first became visible near the rising sun, they recede from that luminary daily towards the south, to a certain extent; then returning eastward they again rejoin it and cease to be seen on that side of the horizon. After being for several days invisible, each planet may be seen to emerge from the light about the setting sun, from which time it again continues daily to recede from that luminary towards the south till the deviation is equal to that which was observed on the eastern side of the horizon; it is then found to return towards the west and, after being again concealed for some days in the solar light, it reappears before sunrise in the east, and the phenomena are repeated in the same order as before. The extent of the deviations of Venus must have been found to be nearly twice as great as that of the deviations of Mercury; and the former, if estimated by comparison with the circumference of a circle in the heavens, whose centre is at the eye of the spectator, would appear equal to about one-eighth of such circumference. At first, indeed, it might have been imagined that the star which appears near the sun in the morning is not the same as that which is, afterwards, seen near him in the evening; but the regularity of the phenomena we have described must soon have led to a conviction of their identity. It is asserted, however, by Pliny[a] that Pythagoras, who learned the fact in Egypt, was the first to make it known to the Greeks.

The times in which the deviations are accomplished would be found to be variable, and they could not be estimated precisely because of the impossibility of observing the planets when very near the sun. But, as the interval between two consecutive appearances of Mercury in the east at sunrise might be found,

[a] Nat. Hist. Lib. II.

nearly, by taking a mean, from several observed times of such appearances, to be about 116 days; the time of that planet's continuance on either side of the sun might be estimated at about 58 days. By a mean taken from several similar observations, Venus might be found to continue on either side of the sun about 292 days.

It must, also, have been observed that the time elapsed between the conjunction of either planet with the sun, at rising, and his greatest subsequent deviation on that side of the heavens, or that, between the greatest deviation on the other side and the next conjunction with the sun, at setting, is much less than the time elapsed between the conjunction and the greatest subsequent deviation on the western side, or that between the greatest deviation and the following conjunction on the eastern side. With respect to the planet Mercury, the former time is about half; and, with respect to Venus, about one-third of the latter time.

Now the observed deviations of these planets from the sun so much resemble the apparent movements of a body revolving in a circular orbit about a central point, when seen by a spectator situated on the exterior of the circumference of such orbit, that it is difficult to imagine why the opinion of the revolution of these planets about the sun or, at least, about some point in a line drawn from the spectator through the sun, was not immediately and universally adopted. The only reason, perhaps, that can be given for the neglect to draw this simple and natural inference from the phenomena, lies in the difficulty which the ancients felt in conquering their prejudice in favour of the notion that the earth was the most dense body in nature and, consequently, was that alone to which all the others would tend to fall if not retained by being attached to a material shell concentric with, and entirely surrounding the earth. It would, indeed, appear from the language of Macrobius[a] that the ancient Egyptians held the opinion that Mercury and Venus moved about the sun, but we are quite ignorant in what sense the expression is to be taken, and it is probable that it only refers to the apparent vibration of those planets on each side of the luminary.

[a] In Somn. Scip. Lib. I.

The periodical movements accomplished by the planets Mars, Jupiter and Saturn with respect to the sun differ considerably from those just mentioned. The time observed to elapse between a conjunction of Mars with the sun and the next following opposition, that is, the interval between his appearance near the sun at rising or setting, and the time at which he is seen to rise when the sun sets, or the contrary, would be found to be about 390 days, a nearly equal time would appear to elapse between the opposition and the next following conjunction, and the interval between the two following conjunctions or oppositions of Mars and the sun might be observed to be about 780 days. The interval between a conjunction and the next following opposition of Jupiter and the sun might appear to be about 199 days, of Saturn and the sun, about 189 days; and the interval between two conjunctions or two oppositions of Jupiter and Saturn would appear to be equal to about 398 days, and 378 days respectively.

To the observations of the abovementioned synodical geocentric motions, must be added those of the sidereal geocentric motions of the planets, which consist in marking the time elapsed between two successive conjunctions with, or near appulses of each planet to any fixed star, these conjunctions could also be distinguished, without instruments, with some precision; and taking the mean times deduced from several observations of each planet, it might be found that Mercury and Venus accomplished one revolution in the heavens from any fixed star to the same, in about one year, Mars, in 687 days, Jupiter, in 4332½ days; and Saturn, in 10759 days. These revolutions appear to have served as the principal guides in the formation of the earliest systems invented to account for the phenomena of planetary movement.

In addition to what has been shewn above, it must be stated that all the planets were early discovered to be occasionally stationary among the fixed stars; and that, at these times, their motions changed from the previous direction to the contrary, but the first observations of these phenomena must have been very imperfect, and, till instruments were used for ascertaining the places of celestial bodies with considerable precision, it is pro-

bable that nothing more was known than that the times during which the planets appeared to have retrograde movements, or to go from east to west, and the spaces described in that direction, were much less than the times and arcs of the direct movements. These changes in the motions of the planets were, however, early considered to be of great importance in the system of the universe; and considerable efforts were then made to determine them with accuracy.

As we have shewn that an attentive consideration of the movements observed in the inferior planets, Venus and Mercury, ought to have led to the opinion that the sun and not the earth was the centre of their revolutions; and as the apparent movements of the superior planets, Mars, Jupiter, and Saturn, with respect to the sun, consist also in a deviation from, and a subsequent approach to that luminary; this circumstance, together with the opinion, then entertained, of the simplicity of nature's laws, might have induced the ancient astronomers to conclude that the latter planets revolved about the sun like the others, with this difference only, that since they are occasionally seen in opposition to the sun, their orbits should include the earth. An argument of this kind must have influenced the philosophers of the school of Pythagoras who, besides, appear to have elevated their minds to the conception of the mobility of the earth, and thus, to have arrived at a system of the universe exhibiting the principal features of that promulgated in later times by Copernicus, and we can, with difficulty, imagine that a system formed by deductions so easily made, could have been first brought to light in an age so late as that of the Samian philosopher. If we leave out the hypothesis of the earth's motion, the observed phenomena should have led to the invention of a system very similar to that of Tycho Brahe, and it is not unreasonable to believe that this has a claim to an antiquity even higher than that of the system ascribed to Pythagoras.

To complete the account of the phenomena which were the subjects of the more ancient observations, there remain to be mentioned the sudden but temporary deprivations of light which the sun and moon occasionally experience: these, indeed, may

have been almost the first appearances which, in the heavens, excited the attention of men, and though many persons even then might have considered them as effects resulting from the general laws of nature, yet the far greater portion of mankind looked upon them as objects of terror, as tokens of Divine displeasure, and as foreboding the heaviest calamities.

It can produce in us no surprise that the most fearful emotions should have been excited by the first appearance of an eclipse of the moon or sun: at one moment might be seen the fair luminary of night, sailing majestically through the skies and diffusing the mild radiance of her enlightened orb over the terrestrial scene, or her silvery image reflected from the unruffled bosom of the waters; and then, while perhaps not a cloud appeared, to afford a cause for any change in the aspect of the heavens, a dark veil might be perceived gradually extending itself over the moon, and reducing her splendid disc, till the whole became covered with the mournful shade; it may, therefore, be easily imagined that, during the continuance of this obscuration, an "untutored mind" might be filled with the apprehension either that some monster was devouring the fair object which used to cheer his nights, or that the vengeance of an angry deity was about to burst upon and overwhelm him. That such fears were felt we may be convinced by the effects which a lunar eclipse is known to produce in the minds of uncivilized people at the present time; and we cannot wonder that, accordingly as men were affected, some should have recourse to such means as they thought capable of driving away the devouring monster, while others should seek to deprecate the dreaded vengeance, by offering sacrifices which they might hope would be acceptable, or by humbling themselves in prayer, till, the veil being removed, the queen of heaven recovered her wonted brilliancy.

But if the obscuration of the moon could create such alarms, when first observed, we may conclude that those excited by the deprivation of the sun's light, in consequence of a total eclipse of that luminary must have been far greater. For while the blazing orb was shedding a flood of glory over the face of nature there might be seen, without any perceptible cause, an

indentation made on some part of the margin of his disc, as if a portion was cut out; and this would gradually increase in size till the whole body of the sun became invisible: it may be conceived that then, the most gloomy apprehensions might take possession of the human mind, since even the brute creation seems, on the occurrence of this phenomenon, conscious of some interruption of the usual course of nature. A total darkness succeeds to the splendour which a short time before adorned the face of the earth, the stars make their appearance; a sense of coldness prevails instead of a fervent heat, the beasts seek their retreats; the feathered tribes which during the day enchant the ear by the harmony of their notes, give place to the birds of night, and it might seem that the next event to be expected by trembling mortals is, that they shall be involved in the destruction which seems to impend over the earth itself. But after a few minutes the sun again appears and his light clothes the fields with new glories. At first a golden thread is seen which, by degrees, increases in size till, after some hours, the orb attains the same circular form which it before possessed; it then finishes its daily course through the firmament and all the phenomena of nature are again repeated in their accustomed order.

Though total eclipses of the sun seldom happen, yet any partial deprivation of his light must have seriously affected the minds of those who first witnessed it, and though the repetition of an eclipse may have been observed with diminished apprehensions of immediate danger, yet the calamities to which the human race is subject are so numerous that eclipses would unavoidably coincide with the occurrences of many disasters, and a connection might easily be conceived to exist between the celestial phenomena and those evils, so that the former might, before the laws of nature were well understood, be taken as presages of the latter. It is, therefore, to be expected that such appearances should be regarded with fear and wonder; and, accordingly, history relates several remarkable effects which have been produced in consequence of the surprise or terror they excited in the minds of ill informed and superstitious men. Thus the solar eclipse which had been predicted by Thales was the cause of a peace between the Medes and Lydians at the

moment when the armies of the two nations were drawn up against each other, and were prepared to mix in deadly strife [a]: and the lunar eclipse which happened during the expedition of the Athenians to Sicily induced the Grecian general, from religious motives, to delay his retreat from Syracuse till it was too late to save his army [b].

The solar eclipses occurring within the few days which elapse between the disappearance of the moon in the east, near the time of sun-rise, and her reappearance in the west, soon after sun-set, must have presently led to the opinion that the deprivation of the light of the sun was caused by the intervention of the moon; it being easy to conceive that, in this interval, at the commencement of which she was seen to be approaching the sun and at the end of which she was receding from him, she might pass between the sun and earth, and thus produce an eclipse of the solar light. The lunar eclipses, also, occurring at the times of full moon, when this celestial body is, with respect to the earth, diametrically opposed to the sun, must have been, by the more attentive observers of nature, from the first, ascribed to the passage of the moon through the shadow cast by the earth, and such explanations do, in fact, occur in almost every ancient writing containing descriptions of astronomical phenomena. "Luna autem, quæ est, ut ostendunt mathematici, major quam dimidia pars terræ, iisdem spatiis vagatur, quibus sol: sed tum congrediens cum sole, tum digrediens, et eam lucem quam à sole accepit, mittit in terras et varias ipsa mutationes lucis habet: atque etiam tum subjecta atque opposita soli, radios ejus et lumen obscurat; tum ipsa incidens in umbram terræ cum est è regione solis interposita interjectuque terræ, repentè deficit [c].

But the opinions of the ancients concerning the nature of eclipses of the moon do not appear to have been completely fixed till about the time of Aristotle. Diogenes Laertius [d] has asserted that the Egyptians were aware of the fact that the moon is eclipsed by passing through the earth's shadow, and Diodorus

[a] Herodotus, Clio, Cap. 74.

[b] Plutarch, Life of Nicias.

[c] Cicero, De Natura Deorum, Lib. II. sect. 40.

[d] In Procem.

Siculus observes [a] that the Chaldeans agree with the Greeks in ascribing the phenomenon to the same cause; but it is probable that these assertions only apply to the people who lived in or near the age of those writers; for though Pythagoras, as both Laertius and Plutarch assert [b], knew that the moon received her light from the sun, and that she was eclipsed when that light was intercepted by the earth, yet the latter, in his life of Nicias, states that the reason why the Athenians exiled Protagoras and imprisoned Anaxagoras, both of whom attributed the eclipses of the moon to the earth's shadow, was, that they considered it impious to suppose a celestial and divine body, like the moon, capable of being affected by this less noble part of the universe; a proof that, whatever might have been the judgments formed by the learned in those days concerning the celestial phenomena, they were unsupported by argument, or at least, that the reasons were unheeded or ill understood by the generality of the people: even the opinion that the moon receives her light from the sun does not appear to have been universally acknowledged, though the variations of her apparent form would seem to prove the fact to any one who should observe those variations with the least attention; and we shall find that there were some who, like the ancient Hindus [c], thought it necessary to suppose the existence of an eighth planet in order to account for the occurrence of eclipses. The obscuration of the moon at a time when both the luminaries are above the horizon, on opposite sides of the spectator, is a phenomenon which has been occasionally observed, and we find mention made of eclipses in such circumstances by Pliny, in his Natural History [d]. Now it is impossible to doubt that they were observed long before his days and, as they must have been thought to militate against the notion that eclipses of the moon were always caused by the shadow of the earth, they may have tended for a long time to produce that embarrassment in the minds of men concerning the cause of eclipses, which prevented the opinions of philosophers, however reasonable, from being generally admitted. Subsequently, the particular phenomenon

[a] Bibl. Hist. Lib II.

[b] Bibl. Hist. Lib. VIII. De Placitis Philos

[c] Asiatic Researches, Vol. XII.

[d] Lib. II cap. 10.

above mentioned received an explanation which is nearly correct; for Cleomedes, speaking of an eclipse of this nature which was said to have at one time occurred, though he seems to consider the fact doubtful, yet admits the possibility that the sun or moon, when under the horizon, may appear to us to be above, since there may be found, he says, to proceed *from the eye*, rays of light, which being broken in the humid atmosphere may follow the luminary and cause it to be seen; adding that many such phenomena may be observed, particularly on or near the sea: to illustrate his meaning he states, and the experiment may be considered as the first of which any account has been transmitted to us concerning the refraction of light, that if, in an empty vase, a ring of gold be put, in such a situation as to be concealed from the spectator, the same will become visible on filling the vase with water [a]. From the time of this writer we hear but of one opinion concerning the general cause of the eclipses of the sun and moon.

The phenomena just mentioned have always been thought worthy of the most attentive observation; and probably, from the first ages, they were registered as historical events We learn that such registers were actually kept by the Chaldeans and it cannot be doubted that, by a comparison of the times at which the eclipses happened, certain cycles or periods of their recurrence were discovered by which they might be foretold. The occultation of stars or planets by the moon, or even the approach of the moon or of a planet to any star, would also be a phenomenon likely to excite the notice of the most ancient observers, not only from the rarity of its occurrence, but also, because it would afford the best means known, before instruments were invented, of ascertaining the precise paths of the moon and planets in their revolutions through the heavens.

Simplicius, in his Commentary on the second book of Aristotle's work De Cœlo, relates, on the authority of Porphyry, that after the conquest of Babylon by Alexander, Callisthenes sent to Aristotle a catalogue of eclipses said to have been observed at that place during a period of 1903 years previously; and this

[a] De Mundo, Lib. II. sect. De lunæ defectu.

was, probably, the fruit of the labours carried on under the direction of the College of Priests attached to the temple of Belus from the epoch of its establishment. The catalogue must have been long since lost, but Ptolemy makes mention of six Chaldean eclipses which seem to have been taken from it, and he employs them in his astronomical work for the purpose of correcting the tables of the moon's mean motions, the oldest of these, however, are said by him to have been observed as late as the years 720 and 719 Before Christ, and La Place[a] remarks that if he had possessed any of more ancient date, on whose precision he could rely, he would, certainly, have used them in determining those elements. As Ptolemy does not expressly mention that catalogue some doubts have been entertained of the reality of its existence; but the silence of the Alexandrian astronomer cannot be considered as of any weight in disproving the fact; for, not to mention the argument before drawn from the probable value of the period of 720,000 years mentioned by Epigenes, we shall find, in speaking of the astronomy of the Greeks, that the elements of the solar and lunar motions had been ascertained with great precision long before any observations are known to have been made by that people; and we shall, consequently, be compelled to admit that they must have been obtained from materials collected by persons who cultivated the science while it was yet unknown in Europe, and therefore, with very great probability, from registers which had been kept by the Chaldeans or Egyptians. From a passage in Diodorus Siculus[b], it appears that the explanation given by the former of these people, of the eclipses of the sun, was so defective, perhaps from their ignorance of the parallaxes, that they had it not in their power to predict them; but, as he contrasts the imperfection of their science in this respect with their knowledge of the lunar eclipses, it is reasonable to infer that they had methods of determining, by computation, the times at which the latter would occur, and were enabled to announce them before hand with some degree of certainty.

From the use which, by the ancient Greek astronomers, was

[a] Exposition du système du monde, page 36. [b] Bibl. Hist Lib. II.

made of the eclipses of the sun and moon, supposed to have been recorded in the Chaldean registers, it is highly probable that the latter contained notices of the times of occurrence; the extent of the obscuration; whether the shadow was central or appeared on the upper or lower limb of the disc; the duration of the darkness, and the place of the moon by her being in the neighbourhood of some remarkable star. But, from the manner in which Ptolemy describes those he has employed, it is not likely that the observations were made any otherwise than by the naked eye, for, in speaking of the quantity, he merely says that one half or one third of the moon's diameter was eclipsed; the distance of the moon from a star is expressed in semidiameters of the former, and the time is given in hours and fractions not less than a quarter. Aristotle mentions[a] an occultation of Mars by the moon, saying the planet entered upon the obscure, and emerged from the lucid side; and he informs us, in the same place, that like observations had been made by the Egyptians and Babylonians who, he goes on to observe, had for many years applied themselves to the study of the heavens, and from whom they, the Greeks, had received many important communications concerning the celestial phenomena. Simplicius also, in his commentary on the first book, relates that the Egyptians and Babylonians pretend to have collected observations on the stars for not less than five thousand years before his time, but he admits that the collection did not contain any thing more than was then well known concerning their magnitudes, colours or motions. In fact, the most ancient observation, now on record, of a planet is an occultation of Saturn which is said by Ptolemy[b] to have been made in the year 228 before Christ: though we cannot doubt that many such observations, made in times far more remote, must have once existed.

The greatest elevation which the moon is found to attain, above the horizon, may be observed to exceed the greatest elevation of the sun, and her least elevation to be less than the least of his, hence a sagacious observer might conclude that the path of the moon in her monthly circuit of the heavens was oblique to that of the sun in his annual revolution, crossing it in

[a] De Cœlo, Lib. II Cap. 12 [b] Almagest, Lib. XI.

two points which are denominated the nodes of her orbit: and the situations of these two points might be ascertained, approximatively, by observing the stars which happen to be near the moon at a time when she is centrally eclipsed, and the place of the sun at his next following eclipse, for the sun, moon, and earth being in the same right line in both these cases, the two former must be at the intersection of each other's paths; and these intersections, or nodes, would be found to be diametrically opposed to each other in the heavens. The places of the planets compared with those of the moon when in their neighbourhood can be conceived to have afforded the means of distinguishing the positions of their apparent paths, and it would be found that they all keep within a small extent, in latitude, on either side of the circle representing the sun's annual path; and, in fact, the breadth assigned to the zodiacal constellations comprehends the traces of all the circles which the planets appear to describe in the celestial sphere.

It must have been impossible, without instruments for measuring the extent of celestial arcs, to have ascertained, directly, that the moon describes her monthly circuit in the heavens with a variable velocity; yet a register of the phenomena of solar and lunar eclipses, kept during a long time, may have led the ancient astronomers to a knowledge of this fact, and, indeed, the notices which, at an early period of astronomical history, are given of the places where the moon's motion is the slowest and the quickest, shew that this important element had not escaped observation. By consulting such a register it might easily be perceived that, in the central or total eclipses, the duration of the passage of the moon over the sun, or of the shadow over the moon, was variable; and consequently that the velocity of the latter, herself, was also variable. Then, if the places of the moon, taken when the duration of the eclipse was the longest and the shortest, were compared, it might be found that they were nearly diametrically opposed to each other in the heavens, a line supposed to join those points is that which was, afterwards, denominated the line of the apsides, and its position might have been, thus, ascertained. The opinion that the real velocity of any celestial body was uniform, being universally

entertained among the ancients; when the eccentricity of the moon's orbit became a received hypothesis, it was concluded that the apparent variation of her velocity depended on her different distances from the earth: hence the points of least and greatest velocity of the luminary were supposed to coincide with those of her greatest and least distances, respectively, of which the former was denominated the apogeum, and the latter, the perigeum. The like points in the circumference of any eccentric circle or orbit were, also, so called; and the angular distance of the moon or of a planet from either, when seen from the earth, was called the anomaly.

To conclude our account of the state of astronomy among the Chaldeans we may observe that this people appear to have noticed from the earliest times some of the comets, those remarkable strangers which so frequently come within sight of the inhabitants of the earth: but the notions entertained concerning them are only to be learned from what has been related by Seneca. This philosopher[a] after remarking that neither Eudoxus nor Conon, both of whom, he says, had diligently studied the astronomy of the Egyptians and had collected such accounts of eclipses as had been preserved by that people, makes any mention of comets, concludes, from thence, that the Egyptians had not cultivated that part of astronomy which relates to their appearances; and then goes on to state that there were two persons, Epigenes and Apollonius of Myndus, who had studied among the Chaldeans, and who do speak of comets, though they differ in the accounts they give of the opinions of that people concerning them, the former alleging that they were considered as bodies kindled in the air, and the latter, that they were of the number of planets or wandering stars. This last opinion coincides remarkably with that which is now universally admitted by astronomers, and, though it could hardly have been expected from the people of that early age, yet it is not impossible that an attentive observer might have been led to form such an hypothesis from a contemplation of the apparent motions of those bodies which, in some respects, resemble the motions of the planets. But when Apollonius asserts that the Chaldeans

[a] Nat. Quæst. Lib. III. cap. 7.

knew the courses of the comets, and Diodorus Siculus[a], that the same people could foretel their risings, or the times when they would become visible, it is evident that they go too far, since, except in a few cases, this is more than can be done by the mathematicians of the present day.

It is remarkable that there is not a word in Ptolemy concerning comets; and this silence makes it probable that, whatever notions the Chaldeans may have formed of them, no account of any observation made by that people to determine their elements, was in existence in the time of that astronomer. But the philosophers of the Greek schools, whose chief talent lay in reasoning concerning the probable causes of natural phenomena, do not seem to have neglected the formation of hypotheses relating to the nature of those bodies, for Aristotle asserts[b] that Anaxagoras and Democritus considered the comets to be produced by the conjunctions of many stars or planets in clusters; and Seneca informs us[c] that Zeno maintained the same opinion; an idea which is not unnatural, since the body of a comet frequently bears a resemblance to some of the nebulous spots in the heavens, and these have, by modern astronomers, been conceived to be formed by an attraction of vast numbers of stars towards the centre of the mass.

But it seems that the opinion of Zeno was contested by some of the philosophers of that day who alleged that the known planets were not sufficient in number to constitute all the comets which had been seen, this engages Artemidorus to assert[d], in support of the ancient opinion, and in accordance with an idea attributed to Democritus, that the number of planets was unknown, and that there may be an infinity of them which, on account of the positions of their circles [orbits] become apparent to us, only while they are describing a certain part of their course; a conception which, if understood of the comets themselves, is very creditable to the sagacity of that philosopher, however he may have merited the censure of Seneca for his notions concerning the constitution of the universe. That the sentiments of some of the ancients regarding comets were much

[a] Bibl. Hist Lib. II

[b] Meteor. cap XVI

[c] Nat. Quæst. Lib VII. cap. 13.

[d] Seneca, ubi sup.

more rational than those subsequently entertained may be inferred from a passage in Aristotle[a] where it is said that the Pythagoreans held a comet to be nothing more than a planet, which reappears after a long interval, and which, at the vertex of the curve it describes, approaches as near the sun as is the planet Mercury: Olympiodorus, on the other hand, in his scholia on the work above quoted, at nearly one thousand years after the time of Pythagoras, considering a comet as the origin of the Fable of Phaeton, observes that this personage is said to be the offspring of the sun because a comet is a sublunary body consisting of dry vapours set on fire by that luminary; his driving through the heavens in the chariot of the sun is made an emblem of the [diurnal] motion of a comet, and his destruction by Jupiter is supposed to indicate that a comet is ultimately extinguished by the moist vapours of the earth. In the writings of the ancients we find no hint, and this circumstance is worthy of observation, that these strange visitants then inspired any of the terror with which, from an opinion that they were the harbingers of evil to the human race, they were viewed by the eye of superstition. The opinion was extensively entertained in Europe before the revival of sound philosophy, but, happily, it has now passed away with many other dreams of ignorance; and the discoveries of Halley and Newton have shewn that comets are of the same nature, and subject to the same laws, as the other planetary bodies of the system to which we belong.

[a] Meteor. Lib. I.

CHAPTER V.

DIVISIONS OF THE CELESTIAL SPHERE.

The ancient manner of estimating the visible distances of the stars from each other, and the visible diameter of the sun.—Manner of dividing the ecliptic.—The lunar mansions.—Determination of the colures.—The extent of the sun's movement northward and southward.—Manner of dividing the circumference of a circle —The circles of the celestial sphere imagined.—Division of the year into months and weeks.—Division of the day into hours.—Difference between the temporary and equinoctial hours.—Advantages of reducing astronomical phenomena to a system.—The hypothesis of material spheres.—The planetary orbits supposed to be circular and eccentric.—Ignorance of the ancients respecting the distances of the planets from the earth.

In estimating by the eye the small distances of stars or planets from each other, and from the moon at the times of the appulses, the ancient astronomers, besides comparing those distances with the visible diameter of the moon, referred sometimes to the measures of length in ordinary use, thus Aratus, wanting to express the distance of a certain star from the nebula in Cancer, says it is about equal to a pygon, or cubit[a]. Now this distance, as is observed by Delambre, is known to be equal to 3° 20′; therefore what was called a cubit in the heavens may be considered as equivalent to that quantity. This mode of designating such spaces appears to have been occasionally employed even after instruments were invented, at least where great accuracy was not attempted, for we find the same expression in the works of the Arabian writers of the middle ages.

Macrobius, in his commentary on the Dream of Scipio[b], explains a method supposed to have been used by the Egyptians for measuring the angular diameter of the sun, which, from its simplicity, is likely to have been very early put in practice: he says they observed on the day of the equinox the direction assumed by the shadow of the gnomon of an equatorial dial at

[a] Phænomena. [b] Lib. I. cap. 20.

the moment the upper edge of the sun appeared above the horizon, and again its direction when the lower edge became visible, then, the angle between these lines, which is that subtended by the diameter of the sun, since the apparent diurnal movement of the luminary is then in the plane of the equator, being compared with the angle made by two shadows of the gnomon at an interval of one hour [15 degrees], gave the measure of the sun's visible diameter. The method is, however, very defective because of the errors produced by refraction, the faintness of the shadow cast when the sun is in the plane of the dial, and the obliquity with which the sun ascends above the horizon; therefore it is not wonderful that the Egyptians should have made the diameter, by such means, three times as great as it really is. According to Cleomedes[a], they succeeded better with the clepsydra, which he says they employed in the following manner: on the day of the equinox they measured the quantity of water which flowed during the rising of the sun's disc and compared it with that which flowed during a whole day; and the proportion of the latter to the former was considered the same as that of the circumference of a circle to the arc which subtends the angular diameter of the sun. The first quantity of water is said to have been between $\frac{1}{700}$th and $\frac{1}{750}$th of the other, and, dividing 360 degrees by these denominators, we find that the corresponding measures of the visible diameter of the sun are equal to 30′ 52″ and 28′ 48″, which are very near the truth, considering the means employed to determine them. The possibility of ascertaining with so much precision the proportion between the quantities of water flowing from the machine is, however, doubtful, though it is probable that the method above described is the only one which would be employed before instruments for the direct measurement of the sun's diameter were invented; and we have no account of any instrument for the latter purpose earlier than the time of Archimedes

Of the magnitudes of the celestial bodies it can hardly be expected that any thing like an approximation to the truth should have been obtained in the times of which we are speak-

[a] De Mundo, Lib. II. cap. 1

ing. Plato, in the *Epinomis*, makes one of the speakers state that the planets had been demonstrated to be of vast size; from which, and from the times they employ in performing their revolutions, he takes occasion to infer that the Deity is the cause of their motions: Lucretius, on the other hand, in the true spirit of scepticism, and because the determinations of the ancients are uncertain, asserts that the heavenly bodies are, in reality, no larger than they appear, to the eye, to be. A method which cannot but appear to us as singularly absurd is proposed by Cleomedes[a] for ascertaining the diameter of the sun, and consists in making a horse run upon a level plane from the moment the upper limb of the sun appears in the horizon till the whole disc is above it; the space the horse is supposed to describe in that time is estimated at ten stadia, and it is inferred, (which, however, implies that the sun is in contact with the earth,) that, if the motion of the earth were equal to that of the horse, the diameter of the sun would be equal to ten stadia It is further stated, but we know not on what ground, that the Egyptians considered the diameter of Saturn to be double that of the moon, and the diameter of the sun to be half the sum of the other two diameters.

The necessity of indicating the paths of the sun, moon and planets must have led very early to an effort at dividing the zone or band of the heavens, within which their movements are performed, into a certain number of equal parts, in order to assign the places of those bodies, at any given time, with more precision than could be obtained by simply naming the constellation they then occupied; this must have been a work of great difficulty before instruments for measuring angles were invented, but we have proofs that the Chaldeans, Egyptians and Hindus had attempted so to divide that zone; and, from a coincidence in the nature of the divisions, if we leave out the improbable statement of Servius that the Chaldeans divided the zodiac into eleven parts, it appears that the principle which guided all these people was the same. Sextus Empiricus asserts, in his treatise *Adversus Mathemat.*[b], that the Chaldeans

[a] In loco citato. [b] Cap. 21.

divided the zodiac into twelve parts by means of a clepsydra, in the following manner; they measured the quantity of water which flowed from the machine in the interval between two successive risings of some one star situated in or near the ecliptic; then, at the rising of the same star on any subsequent night, they unclosed the orifice, and the zodiacal star which appeared in the horizon when one-twelfth of the water had run off, indicated that one complete sign had risen; and, this operation being repeated, the particular stars which terminate each of the twelve divisions were found. But to avoid the errors arising from the irregular flowing of the water from the clepsydra, the following method of approximating to an equal division of the zodiac has been proposed, and it is conceivable that it may have been put in practice by an ingenious people in the infancy of science. About an hour after sun-set, on any day, let a star be observed in the horizon near the place where the sun has disappeared; and if, at the same moment, a star should appear to be rising at a point in the horizon diametrically opposite to that occupied by the other star, these two stars will be in or near the ecliptic. Then, in about thirty days from this time, that is at the end of about one-twelfth part of the year, let the like phenomena be observed for two other stars; and the interval between the two which set near the sun, or between those which were ascending on the opposite side of the horizon, will be equal to about one-twelfth part of the circumference of the zodiac in the heavens; consequently it will form one of the signs or dodecatemories, and in the same manner all of them may be determined. Without denying that a division of the zodiac was early made by the Chaldeans according to one or the other of these methods, it is evident that the portions could not have been equal, as were the signs into which that circle was subsequently, and still is, divided; for, besides the various causes of error which affect the places of celestial bodies near the horizon, on account of the obliquity of the axis of the zodiac to that of the apparent diurnal motion of the sphere of the stars, unequal portions of the zodiac ascend above the horizon in equal times, and those portions are variable in the different seasons of the year; consequently the supposed division

into equal spaces could only have been deduced from the arcs which rise in equal times by calculations of which no traces appear in any account we have of the learning of that ancient people. It is probable that, originally, the divisions of the ecliptic were estimated by the eye and made about the same length that the zodiacal constellations appeared to occupy in the heavens; even after the dodecatemories were used in astronomical works, the unequal divisions were still partially retained; for Hipparchus, in the second book of the commentary on Aratus, makes the extent of Cancer equal to about ten degrees, only, while some of the others exceed thirty, and Ptolemy gives but twenty degrees to Aries while about thirty-nine are included in Taurus.

Now if the star which set near the sun's path and about an hour after him had been observed so to set on the day of the summer solstice, and if a star had been, in like manner, observed about thirty days previously; then the whole dodecatemory between those stars becoming visible six months afterwards, that is at the time of the winter solstice, by its rising at sun-set on the opposite side of the horizon, if a circle were conceived to be traced, in the heavens, between the poles of the earth and any remarkable star which might present itself in the middle of that arc of the ecliptic; this circle would be the solsticial colure, and the star last mentioned might serve to recognize it in the celestial sphere. The position of the equinoctial colure, whose plane is at right angles to the former, might be determined in a similar manner. The colures would thus pass through the middle of the dodecatemories, and it appears that such were the situations assigned them by the Chaldeans and Egyptians: the same disposition of the colures was adopted by Eudoxus, probably from these people, and it prevailed among the Greeks till Hipparchus introduced the practice, which has ever since continued, of placing the colures at the commencement of the signs, and reckoning the longitudes of stars from the place of the vernal equinox. The equator and all circles parallel to it, which are cut by the horizon, might, in the infancy of astronomy, be divided into signs, or arcs of thirty degrees, by observing what stars rose or set at the end of equal intervals of

time, measured by a clepsydra or otherwise; the division of these circles not presenting the same difficulties as that of the ecliptic, because their planes are perpendicular to the axis of the earth's daily revolution, and, therefore, equal arcs ascend above the horizon in equal times.

The methods which served for determining the dodecatemories might have been employed to divide the zodiac into twenty-eight parts; a division which appears to have been early performed in order, probably, to exhibit the extent of the moon's daily motion from west to east. The spaces were denominated the lunar mansions, and they, subsequently, acquired importance from an opinion, maintained by astrologers, that the particular influences exercised by the moon on terrestrial objects, at any given time, depended upon the mansion she then occupied. This division of the ecliptic appears to have originated with the Egyptians, but it was, afterwards, adopted by the Arabians, Persians, Chinese and Hindus, there is no proof that it was in use among the ancient Chaldeans, and some of the Hindus differ from all the other people in reckoning twenty-seven divisions instead of twenty-eight The Egyptians and Hindus also, for astrological purposes, divided each sign of the ecliptic into three equal parts, or *Decani*, so called because they contained ten degrees each, and the latter allotted to each part a regent exercising an influence in subordination to the particular planet which he there represented[a].

The commencement of the dodecatemories and that of the lunar mansions are believed to have been, originally, coincident, and the Egyptians are supposed to have placed their common origin on the circle of celestial longitude passing through the star Regulus, probably because, when they chose the summer solstice for the commencement of one division of their agricultural year, that star was nearly in conjunction with the sun. If we suppose the heliacal rising of Sirius to have taken place precisely on the day of the summer solstice, the epoch of the phenomenon will be found by computation to have been either 2500, or 3000 years before the commencement of our era, ac-

[a] Bailly, Astron. Anc Eclairciss. Liv. IX. sect. 24.

cording as we suppose the star to be distant in longitude 10 or 15 degrees, respectively, from the sun when it first, in Egypt, becomes disengaged from the rays of that luminary before his rising At the former of these epochs, the longitude of Regulus was $86\frac{1}{2}$ degrees, and at the latter, $80\frac{1}{4}$ degrees; consequently the star must, at either epoch, have been situated within a few degrees of the solstitial colure. Now the four intersections of the colures with the ecliptic taking place at the beginning of the first, seventh, fourteenth and twenty-first lunar mansions, it will follow that, in the age just mentioned, the circles of longitude passing through the two extremities of each of those four mansions respectively, passed also near the four principal fixed stars Regulus, Antares, Fomalhaut and Aldebaran· a disposition likely enough to have excited attention, and which probably had some influence in determining the number of the mansions.

Since the first considerable star in the constellation Aries (now marked γ,) has less longitude than Regulus by about 116° 30′, it must have happened that, at the time of the supposed invention of the lunar mansions, the circle of longitude passing through the former star coincided with the commencement of the nineteenth lunar mansion; and an opinion has been advanced, unsupported indeed by direct evidence, yet nevertheless, not destitute of probability, that when, by the retrogradation of the equinoctial points, the equinoctial colure passed through the same star, which was about the year 390 Before Christ, the commencement of the year was, by the Greeks and Asiatics, changed from the epoch of the summer solstice to that of the vernal equinox; a circumstance which did not prevent the origins of the dodecatemories and lunar mansions from being still coincident. In the second volume of the Asiatic Researches is contained an Essay by Sir William Jones, shewing that the ancient Hindus divided the zodiac into twenty-seven Nak-chatras or lunar mansions, of which the first includes the three stars in the head of Aries; and consequently, is coincident with the first of the zodiacal signs: and, in the ninth volume, is a dissertation by Mr. Colebrook, in which the writer endeavours to prove that these Nak-chatras coincide with the lunar

mansions of the Arabs, as they are described by Ulug Beg. Mr. Bentley, in the eighth volume, states that the Hindus ascribe the invention of this division of the ecliptic to Dacsha, who, like Atlas in the Greek mythology, is said to have been a grandson of the daughter of the Ocean a circumstance which gives some force to the opinion that the Hindu astronomy was derived from Greece or Egypt M Bailly observes that though the number of the lunar mansions, according to the Hindus, is less by one than that assigned by the Egyptians and other people, yet, as the former subdivided each of the twenty-seven mansions into four parts, and the Egyptians subdivided each of the twelve zodiacal signs into nine parts, the whole number of divisions is the same, according to both people, which may further serve to strengthen the opinion that the astronomies of India and Egypt had a common origin.

Hitherto we have described merely the apparent intersections of the planes of the equator and ecliptic in the heavens, and shewn how the primitive divisions of these circles were estimated: we have now to mention the steps by which the positions of the principal circles of the sphere were determined; the manner of expressing the measure of any portion of their circumferences, and the means of ascertaining with precision the values of any angular distances between the apparent places of the celestial bodies.

A very slight knowledge of geometry would suffice to shew the extent, from north to south, of the sun's annual path in the heavens. The length of the gnomon, and that of its shadow, form two sides of a right angled triangle from which the value of the angle at the vertex, between the gnomon itself and the ray passing from its summit to the extremity of the shadow, might be determined by a graphical construction according to a method which appears to have been used by Archimedes, and probably was that by which such measurements were first made, that is, by taking with compasses the chord of the arc subtending the angle, and finding how often it could be inscribed in the circumference of the whole circle The difference between the two angles taken on the days when the sun's shadow was the greatest and the least, which is the measure of

the sun's annual movement from south to north in the heavens, might thus be found equal to about one-eighth of the circumference of a circle of the sphere, and this, indeed appears to have been the result originally obtained. But the method of estimating the value of an angle by a fractional part of the whole circumference of a circle seems early to have given place to one more accurate; which was to consider the circumference of a circle as divided into a certain number of equal parts or degrees, 360 for example, and to ascertain the number of those degrees which were contained in the arc subtending the angle: according to this method the difference of the angles made by the rays, with the gnomon, would be found to be equal to about forty-seven degrees, and the inclination of the planes of the ecliptic and equator, which is equal to half that quantity, would be about 23° 30′.

The division of the circumference of a circle into 360 parts, or degrees, may be almost considered as universal among mathematicians, and it is probable enough that, when from the first and rudest observations, the length of the year appeared to be equal to 360 days, the division of the circle into as many degrees was immediately adopted on account of the convenience of expressing the daily movement of the sun in longitude by one of those degrees: after a more correct length of the year had been ascertained, a perception of the advantages of that division, arising from the many simple divisors contained in the number 360 (which rendered it possible to express various arcs by a certain number of degrees without fractions) caused it, with a sexagesimal subdivision, to be retained, and it has ever since continued in use. The great political revolution which took place in France near the end of the eighteenth century brought forth, indeed, a new graduation of the circle, in which each quadrant is divided into 100 parts and each part is decimally subdivided, but, however advantageous this method may be, it has only yet been able to obtain a very partial adoption

It appears from a treatise of Proclus[a] that on some occasions the ancients expressed the values of arcs or angles by numbers founded on a division of the circumference of a circle into sixty

[a] De Sphæra, sect. IX.

parts, and Eudoxus is said to have used that mode of expression; agreeably to which Proclus makes the distance from the pole of the world to the northern point of the horizon equal to six parts (=36°); which is equal to the latitude of Rhodes, the distance of the pole from the point of summer solstice he makes equal to five parts (30°), and the distance of the equator from either tropic, or the obliquity of the ecliptic, equal to four parts (24°) It is probable, however, that such numbers were often employed merely as reductions of the proportions of arcs of circles to their lowest terms. The Chinese have from the earliest period of their history divided the circumference of each great circle of the sphere into 365 equal parts, so that the daily motion of the sun from west to east is nearly equal to one of their degrees; which shews, at the same time, the reason of using that graduation, and that when astronomy was first cultivated in their country, the length of the year was known to be equal to that number of days.

The circle which limits the view of the spectator on the earth's surface, having its plane extended every way to the celestial sphere, was doubtless the first of those which were imagined to be described in the heavens, for the purpose of designating the places of the fixed stars and planets, though it is remarkable that the term horizon, which is applied to that circle, occurs only for the first time in an astronomical work written by the celebrated Euclid. The position of the north point of the horizon, and the direction of the meridian, must have been immediately determined, and this could be done with tolerable accuracy by a method which has been stated above[a]. a line passing through the place of the observer, at right angles to the meridian, would cut the horizon in the east and west points, and the diurnal path of any star, which might be observed to rise in the former and set in the latter of those points, would serve to indicate the position of the equator in the heavens, then, as soon as means were obtained of taking the elevation of a celestial body above the horizon, it would be found that such star, on arriving in the plane of the meridian, had the same elevation as the sun on those two days of the year when he appears, also,

[a] Page 37.

to rise in the east, consequently the sun, on each of those days, appears to describe the circumference of the equator, by his diurnal movement, and these days are found to be equally distant from those on which the shadow of a gnomon is the longest and the shortest; but, as soon as the two days were determined on which the sun rises in the east, a comparison of the angles which, at noon, the gnomon makes with the solar ray projecting the extremity of the shadow, would shew that the deviations of the sun, northward and southward, from the equator were equal to each other on the days of the greatest and least lengths of the shadow, and it would be, no doubt, immediately concluded, by combining the motion of that luminary from west to east with his declinations from the equator, that he must appear to describe, annually, in the heavens a route whose circumference crosses that of the equator in two points diametrically opposite to each other, and whose plane is inclined to that of the latter circle in an angle equal to half the whole movement of the sun from south to north, that is, to about $23\frac{1}{2}$ degrees. The year is, consequently, divided nearly, into four equal parts by the two times at which the sun crosses the equator, and those two at which he attains his greatest declinations: these days might naturally, then, serve to mark the commencements of the four seasons of the year; and, because an equality in the lengths of day and night is observed to take place when the sun is in the equator, the two points in the heavens which the sun occupies on those days received the name of equinoxes, while the term solstice was, as we have said, applied to each of those days on which the sun's declination is the greatest. The circles which the sun appears to describe, in his diurnal course, on the days of the solstices, received the name of tropics from a word signifying a return, because, from the solstitial points, the sun seems to return towards the equator. To the oblique route described annually by the sun through the heavens the name of ecliptic was given because the eclipses of the sun and moon take place, always, in or near its circumference.

The positions of the equator and ecliptic being determined, it was easy to conceive the existence of other circles in the celestial sphere respectively perpendicular and parallel to the

planes of the two former, and to refer to them the places of the celestial bodies, by the coordinate distances of the latter from such of the circles as were considered to be the primitives: the distances were denominated longitudes and latitudes, with respect to the ecliptic; right ascension and declination, with respect to the equator. And after the spherical form of the earth was recognized, the planes of the celestial equator and of the circles perpendicular to it were imagined to cut the earth and form on it the terrestrial equator and circles of terrestrial longitude, also, by lines supposed to be drawn from the centre of the earth to the circumferences of circles, in the heavens, parallel to the equator, corresponding circles would be conceived to be marked out upon the surface of the earth and form there what have been called circles of terrestrial latitude; these circles on the earth serving to fix the geographical positions of places, as those in the heavens served to determine the situations of the celestial bodies.

The position assigned by the ancients to the arctic circle in the heavens is not the same as that which this circle is now supposed to occupy, at present its distance from the pole of the world is made equal to that of either tropic from the equator, but Proclus states [a] that Eudoxus considered it to be at a distance from that pole equal to the latitude of the place of observation, so that it must have touched the horizon of that place on the northern side, and must have formed the southern limit of the circumpolar constellations, or those which are always visible by night. It is thus described by Manilius:

> Circulus ad boream fulgentem sustinet arcton,
> Sexque fugit solidas a cœli vertice partes [b].

The six parts here mentioned are equal to $\frac{6}{60}$ of the whole circumference, according to the division of the circle used by Proclus and ascribed to Eudoxus, that is, they are equal to 36° according to the common graduation, which indicates that the place of observation must have been situated in the parallel of the latitude of Rhodes. The astronomical poet also states, in the same book, that the northern tropic is distant from the arctic

[a] De Sphæra.

[b] Astronomicon, Lib I ver. 564.

circle by five parts, and the equator from the tropic by four parts, which must be understood, in like manner to be equivalent, respectively, to 30° and 24°, a quadrant of the meridian being divided into fifteen parts, according to Eudoxus.

We have said that some nations divided the year into months of thirty days each, the commencement of each month being probably determined by the appearance of the new moon; and it seems that half synodical revolutions of that luminary were, by the ancient Hindus [a], on some occasions, used as measures of time. It has, also, been supposed that, as soon as the period of a sidereal revolution of the moon, which is equal to about twenty-eight days, was observed, the four principal phases of that luminary were made to serve the purpose of dividing the month into weeks of seven days each, but it is probable that this last cycle may lay claim to a higher origin, and that its first use may have been derived from an appointment of the Deity himself The knowledge, however, of the first revelation granted to man being lost to the heathen world, it was natural that a celestial observation which it was in the power of many persons to make should be thought to have given rise to the employment of the period, and that the invention of it should have been ascribed to that people among whom a knowledge of it was first found to exist. Dion Cassius states [b] that the week of seven days was invented by the Egyptians, but, in whatever way it may have been introduced, it is certain that it has been received by all people who have a notion of a calendar; and it has been proved by La Place to be identical in all calendars both with respect to the denominations of the days and their correspondence to the same physical instants of time.

According to the testimony of Horus Apollo, who lived in the fourth century of our era, and wrote upon the Egyptian hieroglyphics, the Cynocephali (supposed by Mr. Bryant [c] to have been members of a royal seminary in Upper Egypt,) were addicted to the contemplation of the heavens, from which they learned to distinguish the seasons and to divide the day into twelve parts or hours. But in the writings of the Jewish and

[a] Quint Curt. Lib VIII. cap 9. [b] Hist. Rom Lib XXXVII.

[c] Analysis of Ancient Mythology, Sect. Phœnix and Phœnices.

Arabian astronomers of the middle ages the division of the day into twenty-four hours, and the denominations of the days themselves, are ascribed to the Chaldeans, who are said to have called each hour by the name of a planet and to have given to each day the name of that planet from which its first hour was designated. From the arrangement of the days of which the week is composed, it is evident that a disposition of the planets similar to that assigned in the system of Ptolemy must have been prevalent at the time the denominations were imposed; for if we reckon the planets in the order which they have in that system, viz. Saturn, Jupiter, Mars, the Sun, Venus, Mercury and the Moon, the first hour of the first day would be designated Saturn, and the name of Saturn was given to that day; then, in twenty-four hours, the planets would be passed over three times, and there would remain three hours, so that if the day began with Saturn the last hour would be called Mars; therefore the first hour of the second day would be given to the sun, and that was the name of the second day, again, reckoning as before, the last hour of the second day would be Mercury, and the first hour of the third day would be given to the moon; so that the third day received the name of the Moon, and so on. Thus the several days had, in succession, the names of the Sun, Moon, Mars, Mercury, Jupiter, Venus and Saturn; and this arrangement must have been communicated from the people who first proposed it, to the Egyptians, Greeks and Romans; for these could not have been led, independently, to the adoption of the same names of days, from the order of the distances of the planets, since they did not, all, suppose this order to be the same. Almost all the people of the ancient world supposed the day to begin at sun-rise, no doubt because that phenomenon was a most distinguishable mark offered by Nature herself to divide the period of a revolution of the heavens into two great portions; and the interval from sun-rise to sun-set was considered as the length of the day, but when machines had been invented for the purpose of dividing the day into equal parts, this method was found to be very inconvenient because the days are of unequal length, not only in places differently situated with respect to latitude, but also at the same place in different

seasons, and it was finally superseded by that of reckoning the hours of the day from noon or midnight. Hipparchus appears to have been the first who assumed the latter epoch for the origin of the day, but astronomers now invariably reckon the hours of the day from the former.

Two methods of dividing the day into hours seem to have been employed in very early times For civil purposes, the interval between sun-rising and sun-setting was divided into twelve equal parts, each of which, of course, must have been, every day, of a different length; the interval between sun-setting and sun-rising was divided in a similar manner, and it is evident that the nocturnal, could not have been equal to the diurnal hours except on the days of the equinoxes Such equal divisions of the natural day were called temporary hours, and they were determined by a clepsydra or some similar machine, the dimensions of the aperture through which the water was allowed to flow being made to vary with the varying length of the day. Such divisions of the day are alluded to by Achilles Tatius, who endeavours to illustrate their nature by comparing them to the fingers of the hand which are always the same in number, but are not all of equal lengths. The ancient astronomers, however, generally used what are called equinoctial, or solar hours; which are those determined by a sun dial, and instruments of this kind appear to have been in use from a very remote period.

In the progress of astronomy, the discovery of the principal phenomena of the celestial bodies seems to have been followed immediately by an effort to account for such phenomena by some physical cause; and the formation of an hypothesis which satisfied the observations, while it gratified the pride of man by making him appear to be acquainted with the secret mechanism of nature, must have facilitated the improvement of the science by enabling succeeding observers to connect the isolated facts they brought to light so as to unite them in one system: by this, the original hypothesis may have been proved or, if necessary, modified, and from thence it became possible, by reasoning, to deduce some of the circumstances relating to the planetary motions which were inappreciable by the instruments employed,

or which, otherwise, would have remained for ages undiscovered by observation.

The general motion of the celestial bodies about the earth, from east to west, it would, immediately, be attempted to explain by supposing them to be attached to the concave surface of a hollow sphere which, being endowed with that movement of revolution, would, consequently, carry all those bodies along with it; but the movements of the planets being found to be variable in velocity and direction, it would be necessary to suppose them independent of the sphere of the inerratic stars and, either to move by themselves in free space, or each of them to be attached to a separate sphere by whose motion it might be conveyed about the earth: the latter supposition seems to have been immediately preferred, probably because no satisfactory reason could, at first, be assigned why, if left to themselves, they should not fall from their places, agreeably to what was constantly observed of bodies near the earth's surface when left without support.

But whether attached to spheres or not, the phenomena of the movements of the superior planets might, naturally enough, lead to the opinion that these movements were performed about the earth in orbits which were perfectly or nearly circular; because, at different times, they appear to be in every different part of the circumference of an imaginary circle in the heavens Now the first opinions of men concerning the heavenly bodies seem to have been drawn from a supposed perfection in all their qualities rather than from observation of their phenomena, and it became an established point that the movements must be performed in orbits correctly circular, and with uniform velocities, hence, from the observed variability of the planets' motions, it was early concluded that the circular orbits could not be concentric with, though they were supposed to enclose the earth; for by making an orbit eccentric, it is evident that a body, really moving with a uniform angular motion about the centre, would appear to move faster, when in that part of the orbit which is nearer the spectator, and slower, when in that more remote than the point of mean distance from him. The changes in the apparent movements of the planets from direct to retrograde,

and the contrary, did not, perhaps, for some time excite attention. The opinion that the real velocities of the planets were uniform must have had its supporters as late as the time of Pliny, for that distinguished philosopher observes [a] that the planets appear to move slowest when in the highest circuit [in apogeo], not because there is any acceleration or retardation of their true motions, which are uniform for each planet, but because, at different distances from the centre of observation, unequal angular movements are described by the radii drawn to the planet.

Now, with respect to the inferior planets, the fact that they never deviate beyond a certain distance from the sun, and that they alternately approach to, and recede from him, might be supposed to afford an argument that their movements depended, in some measure, on that luminary; and could the phases the inferior planets present to a spectator on the earth, and their transits over the sun's disc, have been seen without the aid of a telescope, the former, from their resemblance to the phases of the moon, and the latter, from their occurrence between the disappearance of the planets in the sun's light at his rising, and their emergence from thence after sun-set, would, at once, have led to the discovery that those planets revolve about the sun, but this being impossible, it is less surprising that the true nature of their movements should have been mistaken or quite unknown. Any observations made by the naked eye would be insufficient to determine whether the movements were rectilinear or circular with respect to the sun, and, if a circular movement were supposed, it would be still uncertain whether the sun was, or was not, included within the orbits: but, admitting that the inferior planets revolved about the earth, it must have been obvious that they were carried with the sun in his annual course; and this appearance probably led to the opinion of the motion of the planets in epicycles, which afterwards became so general.

It was impossible for the ancients to have any proof of the different distances of the planets from the earth, except such as

[a] Nat. Hist. Lib. II. cap. 13.

might be obtained from the difference in the degrees of their brightness, or of their apparent velocities about the earth; having adopted the principle that the paths of all the celestial bodies were circular, and their true movements uniform and equal, it would seem to follow that those which had the slowest motions were the most remote. The ancients invariably arranged the superior planets in the same order. Saturn was supposed to be on the exterior, then followed Jupiter and Mars, in succession towards the earth, which was placed in the centre of the system; they all agree, likewise, in considering that the sun and moon revolved with the other planets about the earth in orbits within that of Mars, and that the moon's orbit was the nearest to the earth. But a difference of opinion existed among the ancients about the disposition of Venus and Mercury; according to Achilles Tatius [a], some of them placed the sun between the spheres of those planets, but, he observes [b], the Egyptians placed the latter between the spheres of Mars and the sun, probably because Venus and Mercury were never seen to pass over the sun's disc, and they supposed the former to be nearer the earth than the latter perhaps because it appears brighter; this disposition was adopted by Plato and is mentioned in his dialogue Timæus: on the other hand, in the system of the later Greeks, and, as Alpetragius states, in those of the Babylonians and Hindus, the orbits of Venus and Mercury are placed between those of the sun and moon; that of Mercury being nearest to the moon or earth because his conjunctions with the sun occur more frequently than those of Venus.

[a] Tatius, Isagoge, cap 16. in Petav. Uranolog. [b] Ib. cap. 17.

CHAPTER VI

NATURE OF THE ANCIENT ASTRONOMICAL CYCLES.

Determinations of the solar and lunar years.—Probability that the Sothaic period was used by the Egyptians.—The Persian cycle.—Possibility that the Egyptians had discovered the movement of the equinoctial points.—The commencement of the year was variable among the ancients.—The Egyptian agricultural year regulated by the heliacal rising of Sirius.—The Chaldean cycles.—Ancient planetary cycles.—The restitutions of the moon's inequalities of movement supposed to have been known to the Chaldeans and Hindus.—The ancient manner of determining the moon's periodical revolutions.

The manner in which the ancient Egyptians and Chaldeans determined the length of the year is doubtful, but there are two methods capable, as we have shewn, of affording an approximation to it, and either of them might have been adopted in the infancy of astronomy; these are the heliacal risings of stars and the lengths of the shadows of a gnomon. The interval between two heliacal risings of any star would include a period nearly equal to that which is known by the name of the sidereal year; and that between the days of the two longest or two shortest shadows, which indicate the days of the winter and summer solstice respectively, would give the length of the tropical year. If we are not allowed to suppose that a gnomon was used for the purpose of ascertaining the tropical year, or that on which the seasons depend, we may remark that the same could be rudely determined as soon as men had learned to trace a meridian line, or one at right angles to it; for, by simply looking, at morning and evening, in the latter direction, the days of the vernal and autumnal equinox would be known since, then, the sun rises and sets precisely in the eastern and western points of the horizon. It has been supposed that the faces of the Pyramids of Egypt had their particular directions in order to allow this kind of observation; and M. Biot remarks [a], that two of the faces of the temple at Denderah were disposed so that the

[a] Recherches sur l'Astronomie Egyptienne.

horizontal lines passing along the foot of their walls tended southward of east and northward of west about as much as the amplitude of the sun at rising and setting on the days of the winter and summer solstice respectively, consequently those days might be found and, from thence, the length of the year, by simply directing the sight in a line parallel to the same faces. This method of determining the year is by Simplicius [a], expressly stated to have been practised, and it is probable that it gave rise to the formation of a year of six months, which was that used by the Carians and Acarnanians, and in which as Censorinus observes [b] the days increased during one year and decreased during the next, alternately, for such would be the case if the first year was made to commence at midwinter, and the other at midsummer. The difference between the sidereal and tropical year being only about twenty minutes, by which the former exceeds the latter, on account of the retrogradation of the equinoctial points, would be long imperceptible from the uncertainty of the day on which any star first rises heliacally and the uncertainty of the precise moment when the shadow of the gnomon is the longest or shortest.

By the testimony of Diodorus Siculus [c] the year of the Chaldeans and Egyptians originally consisted of thirty days, it must, therefore, have been formed by taking that number of days as a lunar period, or interval between two consecutive changes of the moon; and this writer, in the same book, assigns to the latter people the honour of regulating the year, subsequently, by the sun instead of the moon, he alleges that they made the solar year consist of twelve months, of thirty days each, and added five days and a quarter after each twelfth month, to complete the circuit. But it seems as if a year of 360 days only, was, for a certain time, used in Egypt and, as it is not likely that an error of five days should have been made in determining the length of the solar year by any of the methods above mentioned, we can only imagine that such a length was purposely chosen for the sake of the round number. The sun is said by Manetho to have been the son of Vulcan and the in-

[a] Comment 46, Lib. II. De Cœlo. [b] De Die natali, cap. 16

[c] Biblioth. Hist. Lib. I

ventor of fire; he married Rhea and, having discovered her infidelity, condemned her to bear no offspring on any day or night of the 360 which then constituted the year[a]: and the following remarkable story is related by Plutarch[b] concerning the introduction of the epagomenæ or additional days Mercury, he says, engaged himself, in a contest at dice, with the moon, in order to gain time for the birth of Rhea's children, and evade her husband's curse, being victor, he took off $\frac{1}{70}$th from each day, and of these portions made five whole days, which he added to the 360 previously composing the year. It is said that Osiris was born on the first supplementary day, and Typhon on the third. The fable will, at least, serve to prove the fact, that the year of 365 days was an improvement subsequently made upon that which had been more anciently used

But it was not in Egypt alone that the year of 360 days was in use, for Diodorus Siculus alleges[c] that, among the Chaldeans, it succeeded to the lunar year of thirty days, and M. Bailly supposes that their knowledge of it was acquired in the reign of Evechous, the first king of Babylon, who, he thinks, was contemporary with an ancient Zoroaster, and lived in the year 2459 Before Christ. Diŏdorus adds that 33,583 years of the former kind are equal to 403,000 years of the latter kind, and the expression of these periods by such high numbers, when the ratio of 1 to 12 would have been quite as accurate, seems to indicate that the writer had in view some epoch, real or imaginary, which entered into the astronomy or chronology of that people. That the Egyptian year of 365 days was introduced into that country before the time of Alexander is proved from a passage in Quintus Curtius, where the march of the Persian army is thus described[d]. "Patrio more Persarum traditum est, orto sole demum procedere Die jam illustri, signum e tabernaculo regis buccina dabatur; super tabernaculum, unde ab omnibus conspici posset, imago solis crystallo inclusa fulgebat. Ordo autem agminis erat talis Ignis, quem ipsi 'sacrum' et 'æternum' vocabant, argenteis altaribus præferebatur. Magi proximi patrium carmen canebant. Magos *trecenti et sexaginta*

[a] Eusebii Chronici pars I.
[b] De Iside et Osiride.
[c] Bibl. Hist Lib. I.
[d] De Rebus Gestis Alexandri, Lib III. cap. 3.

quinque juvenes sequebantur, puniceis amiculis velati, *diebus totius anni pares numero. quippe Persis quoque in totidem dies descriptus est annus.* Currum deinde Jovi sacratum albentes vehebant equi: hos eximiæ magnitudinis 'equus,' quem 'solis' appellabant, sequebatur: aureæ virgæ et albæ vestes regentes equos adornabant."

It is probable that, originally, the Greeks considered a synodical revolution of the moon as one year, and that they, afterward, formed periods of time consisting of three months each. Censorinus[a] relates this circumstance, and adds that the Arcadians had acquired the denomination of *Proselenas;* not, says he, because it was supposed that they were a nation before the moon became a star in the heavens, but because they, first, in Greece, used a year which was determined by the course of that luminary. The year of 360 days appears also to have been in use among the Greeks, since Hesiod affirms the fact[b] and mentions a division of it into twelve months. This people, however, subsequently adopted a lunar year of 354 days, divided, also, into twelve months, but they long persisted in the imperfect practice of considering each month to have 29 days, and of intercalating a month every alternate year in order to make their civil reckoning correspond nearly with the solar period; a method alluded to by Diodorus, in his first book. But the defects of this method soon becoming sensible, Solon abandoned the intercalation, retaining only the simple lunar year and regulating that the twelve months should, alternately, consist of thirty days and twenty-nine days. The tropical year, however, was, at length, introduced into Greece, from Egypt, for Strabo[c] relates that Plato and Eudoxus had resided thirteen years at Heliopolis, where they learned from the priests of the country what portion of a day was to be added to 365 days in order to complete the solar year; which was, as he alleges, till then, unknown to the Greeks. Now, as the latter people, from the time that they used that kind of year, always, in their civil accounts of time, supposed it to consist of $365\frac{1}{4}$ days, it will follow, either that the Egyptians did not

[a] De Die Natali, cap. 16.
[b] Opera et Dies, Lib. II.
[c] Geograph. Lib. XVII.

communicate a more accurate knowledge of the length of the year, or that, if they did so, no public use was made of it in Greece. Pliny states[a] that, according to the Egyptians, the solar year was rendered complete in a period of four years, and that this period produced the return of the winds and bad weather to the same days, alluding, no doubt, to its advantages over the *annus vagus*, or sacred year, which consisted of 365 days without a fraction He observes, also, that the period of four years, when introduced into Greece, had the name of the Tetraeteris of Eudoxus, and this philosopher may, therefore, be supposed to have brought it from Egypt. The Egyptians themselves, ascribe the discovery of the additional quarter of a day, as well as most of their improvements in the sciences, to one of their Hermes. But, according to Geminus[b], they designedly used a year of 365 days without a fraction, in order that their religious festivals might not be fixed to one season of the year. This writer alleges that it was a common error among the Greeks to suppose that the festival of Isis happened always at the winter solstice; this, he says, was true 120 years before his time; but he observes that it now takes place about a month earlier, and as Geminus lived about 77 years B. C it is evident that the period at which the festival so occurred must have been nearly 200 years B. C. Formerly, he adds, on the authority of a commentary on the Octaeterides, or cycles of eight years, ascribed to Eratosthenes, the same festival was celebrated as early as the summer solstice: and as the quarter of a day, by which the Julian year exceeds that of the Egyptians, will amount to half a year in 730 years of the latter kind, it is evident that the epoch alluded to by Eratosthenes must have been about the year 930 B. C. or at a period earlier either by 1460 years or by some multiple of that number of years. The ancient Hindus used both a solar and a lunar year, and they considered each to be divided into 360 parts called days; but these appear to have been fictitious, and used only for the purpose of facilitating certain astronomical computations: it is probable therefore that such a division was not made by that people till the science

[a] Nat. Hist. Lib. II cap. 17.

[b] De Apparentiis Cœlestibus, cap. De Mensibus.

was so far advanced among them that it became necessary to have recourse to it for the purpose of simplifying the rules by which the times of celestial phenomena were computed.

Whether the Egyptians determined the length of the year by the heliacal risings of stars, or by the occurrence of the equinoxes or solstices, while they continued to use that which was denominated the sacred year, and consisted of 365 days, they could not avoid observing, at the end of a certain number of such years, that their festivals ceased to fall in the same season as that in which they were at first celebrated, in fact, in 360 years, any religious or other rite which was appointed to take place on a certain day, suppose that of midsummer, would anticipate the season by about three months, and would then actually occur at the beginning of the spring quarter, and, since 360 years are to three months, as one year is to a quarter of a day, this people might find that the length of the year ought to be equal to about 365¼ days, in order to make their calendar accord with the seasons, which, though of little moment in the arbitrary regulation of religious ceremonies, must have been always of the utmost importance for civil purposes. Since also, 1460 years of 365¼ days, each, are equal to 1461 years of 365 days each, it will be easy to perceive that at the end of 1460 years, the festivals of the sacred year would return to the same seasons as at the commencement This forms, in all probability, what was called the sothaic or canicular period; the knowledge of which cannot be denied to the Egyptians; and attempts have been lately made to ascertain the age in which the period was introduced among that people; the enquiry is interesting, but, from the account we are about to give of the foundations on which it rests, it will be perceived that no satisfactory conclusion concerning it has been obtained.

The late discoveries of M. Champollion have shewn that the ancient Egyptians commenced their civil, or agricultural year, with the season for sowing corn, that is immediately after the subsidence of the Nile, and while the ground was yet moist from the action of the waters. Now as the rising of the river depends on the rains which fall regularly, in Abyssinia, during the summer, commencing invariably with the summer solstice,

and attaining its highest elevation in about one hundred days; it is evident that the civil year must have been the same as that which is called the tropical year, that is, it must have consisted of about 365¼ days: this period the Egyptians divided into three parts which were represented by symbols illustrative of the periods of vegetation, harvest and inundation; each of the two first periods comprehended 120 days, and the third, 125¼ days, of which the five last were the epagomenæ or supplementary days, and M. Champollion, therefore, considers that the beginning of the civil year was fixed at the one hundred and twenty-fifth day after the summer solstice. But the sacred year of the Egyptians, as we have said, consisted of 365 days only; its commencement was, consequently, variable, retrograding regularly about one day in every four years; and if we suppose that, at the introduction of the sacred year, its commencement coincided with that of the agricultural year, it would follow that a like coincidence could only again occur at the end of every period of 1460 tropical years, supposing with the Egyptians, each of the latter to be exactly equal to 365¼ days: or at the end of every period of 1506 years, if we make the length of the tropical year equal to what is now known to be its true value.

M. Champollion, in attempting to find the time when the sacred year was introduced, sets out by assuming the well known fact, that in the twenty-fourth year before the commencement of our era, when Augustus altered the Egyptian calendar, and put an end to that mode of reckoning time, the first day of the month Thoth, that is, of the sacred year, coincided, according to the Julian calendar, with the 29th day of August which was then sixty-five days after the day of the summer solstice [June 25], then, on account of the 12 minutes by which the Julian year exceeds the length of the tropical year, and which causes the day of the equinox or solstice, in times posterior to the introduction of the Julian calendar, to retrograde about one day in 120 years, it is evident that, in the year 275 B.C. the summer solstice must have occurred on the 27th day of June, and he computes that, at this epoch, the first day of the sacred year must have coincided with the 31st day of October, which is just

125 days after the solstice; and, consequently, was the first day of the agricultural year. If, therefore, he observes, the introduction took place at the epoch of a coincidence of the two kinds of year, and, if we suppose that the intervals of the coincidences are, each, equal to 1506 years, we should have, for the preceding epochs of coincidence, the years Before Christ 1780, 3285, 4790, &c. respectively.

Censorinus however asserts[a] that the first year of one of the sothaic periods fell just one hundred years before that in which he wrote, and which he designates as the year 986 of Nabonassar [A D. 239], so that the commencement of a period must have coincided with the year 139 of our era; and he adds that, at the latter epoch, on the twelfth day of the kalends of August [July 20], the first day of the sacred or variable year (the memory of which seems to have been retained in Egypt though its use was abolished by law) was coincident with the day on which Sirius rose heliacally in that country; and, in fact, it is found by calculation that the phenomena actually took place in Egypt, in that year, about the day specified; that is, twenty-seven days after the summer solstice; therefore, if we suppose that the interval between two consecutive heliacal risings of that star was then exactly equal to 365¼ days, which M. Biot proves to have been very nearly true between the years 2000 and 3000 Before Christ; and that, consequently, the sothaic period, determined by the returns of the heliacal rising of the star to the same day of the annus vagus, was equal to 1460 years; by reckoning backward we should have the years Before Christ 1321, 2781, 4241, &c. respectively, for the previous epochs at which the like coincidence took place; and one of these is imagined to have been the epoch of the first introduction of that kind of year.

But it has been supposed, and the opinion is founded on a passage in the Scholiast on Aratus, probably Theon of Alexandria, that the commencement of the agricultural, or, as it was also called, the canicular year, was coincident, in time, with the heliacal rising of Sirius; and, according to Diodorus Siculus, the Egyptian priests had a tradition that the rising of the Nile was originally coincident with the same celestial phenomenon. Now

[a] De Die Natali, cap. 17.

if the day be that on which the increase in the height of the waters is first perceived; that is the day of the summer solstice; it would follow that the agricultural year commenced at midsummer: and, adopting the data afforded by Censorinus, we should find that the coincidences of the first day of the *annus vagus* with that of the former year, so commencing, would be in A.D. 31, and in the years Before Christ 1475, 2981, &c. which agree with neither of the other epochs: we are, therefore, left to make our choice among them for the time at which the sacred year was introduced into Egypt, without a single condition to determine our opinion in favour of either.

Several circumstances conspire to render all these determinations unsatisfactory, for, besides the absence of all proof that the coincidence above mentioned was coeval with the establishment of the Egyptian calendar, the heliacal rising of a star and the first perceptible rise of the Nile are uncertain within several days, by which the epoch founded on either event is also rendered uncertain to the amount of as many hundred years: the length of the agricultural year is also undetermined and consequently the sothaic period itself is susceptible of different values; if the year was made to depend on the rising of the Nile, it must have been strictly tropical; if on the heliacal risings, it must have been exactly equal to 365¼ days, and no one can say by which of these circumstances its length was regulated, it is certain, moreover, that the ancient Egyptians made no distinction between the tropical and canicular years, and that they were not even aware of the difference between them.

The Scholiast on Aratus connects with his remark that the origin of the canicular year was coincident with the heliacal rising of Sirius, two additional circumstances, the overflowing of the Nile and the presence of the sun with the *star* Leo; either meaning that the sun was merely somewhere in the constellation bearing that name, or, in conjunction with Regulus, the principal star in it. Now we find by computation that, about the year 2500 Before Christ, Sirius rose heliacally precisely on the day of the summer solstice, and that the longitude of Sirius was then 41° 30′, which is less than the longitude of the sun by 48° 30′;

the sun must therefore, at that epoch, have been situated near the middle point of the constellation, and have been nearly in conjunction with Regulus; and it is, probably, from this circumstance, and because the star lies nearly in the sun's path, that it was distinguished by the epithet *royal.*

In all the period between about the year 4000 B. C. and the age of Theon, the sun must have been in the constellation Leo at the time of the heliacal rising of Sirius; but the connexion of the latter phenomenon with the rising of the Nile cannot be supposed to have been observed earlier than 2500 years Before Christ, when the rising of the star took place on the day of the solstice; since, the elevation of the waters not being great enough to attract general notice till after that day, it is not likely that the elevation should, when first observed, have been suspected to depend in any manner on the rising of the star; and it may be rather supposed that such dependence would not be noticed till a later age, when, on the first appearance of the star in the evening, the waters had attained a perceptible height; and when, consequently, the people of the country might consider the two circumstances to stand to each other in the relation of cause and effect, and thus be led to give to the agricultural year a designation drawn from the name of the star. The fixation of the commencement of the agricultural year to the day of the solstice, or, as Champollion supposes, to the hundred and twenty-fifth day after it, may have taken place as soon as the Egyptians applied themselves to the cultivation of the ground, and long before the rising of Sirius was regarded, but the first use of the *annus vagus* if it be supposed to be connected with this phenomenon, cannot be dated from a period more remote than the year 1321, or 1475, B. C. reckoning backward from the coincidences mentioned by Censorinus; or than the year 1780 B. C if we adopt the hypothesis of Champollion.

It must be admitted also, that there is no direct proof, in any author who lived before the commencement of our era, that the Egyptians paid any attention to the sothaic period, but the allusions made to it by subsequent writers leave little doubt of the fact. The fable mentioned by Tacitus[a] concerning the

[a] Taciti Annalium Lib VI. cap 28.

phœnix, which was supposed to rise from its ashes at the end of 1461 years, seems to be an allegory intended to express the duration of the cycle; and, besides the account given by Censorinus as above stated, the remark made by St. Clement of Alexandria, who lived at the beginning of the third century, that Moses was born 345 years before the establishment of the sothaic period, implies that this last had been anciently used in chronology. According to most of the commentators, the Jewish lawgiver lived about 1570 years Before Christ; therefore, if any dependence could be placed on the testimony of the above mentioned Father, it would seem that the cycle was instituted about 1225 years Before Christ. This epoch differs not more than one hundred years from one of those which have been inferred from the passage in Censorinus; and the two accounts may be reconciled by supposing that the introduction of the cycle did not take place for many years after the observed coincidence which determined its commencement. An indirect argument in favour of those who contend that the cycle was really employed may also be drawn from a passage in the historian Syncellus, who lived in the eighth century: this writer, in an extract from the works of Julius Africanus, states that the latter had copied a relation given by Manetho, in a chronological work composed by order of Ptolemy Philadelphus, and professing to have been taken from a more ancient Egyptian chronicle, in which it was asserted that from the reign of the sun to that of Nectanebus II. there had elapsed 36,525 years; and since this number is equal, as Syncellus observes, to the product of 1461 by 25, or to twenty-five sothaic periods, there seems reason to believe that the cycle was in use in, or before the time of Manetho.

If the authority of Hyde is of any weight, it would appear[a] that Jemschid, one of the most ancient monarchs of Persia, introduced into that country, for religious purposes, a vague year of 365 days without fractions, for the same reason that this mode of reckoning time was used by the Egyptians: and that, for the general use of the people, he formed another kind of year, whose commencement was to be fixed by an embolismic month, added

[a] Historia Religionis Vet. Persarum, cap. 14.

at the end of every 120th year. That is, as Hyde explains it[a] in a quotation from a work of Mahmud Shâh Cholgius, the year was supposed to consist of 365¼ days and was divided into twelve months of thirty days each with 5 additional days; but the remaining quarter of a day making, in 120 years, just 30 days, or another month, this was added as an embolismic month, by reckoning the last of the year twice over, at the end of the first 120 years; at the end of the next 120 years, two months were added and so on till after 1440 calendar years, when twelve months or one whole year was reckoned twice; and thus 1440 years constituted the period of an intercalation. This manner of correcting the calendar is said[b] to have continued till the time of Jesdegird, after whose death a new era commenced, with the year 632 A.C. and then, the intercalated month fell at the end of the eighth month of the Persian year, which year was, consequently, the 960th of one of the above mentioned cycles: hence M Bailly concludes[c], that the Persian mode of intercalation commenced either in the year 329 B.C. which must have been the first year of a cycle, or in a year earlier by 1440 years or by some multiple of that number of years; and the French astronomer who, when the probabilities are equal, always chooses a very ancient epoch, supposes the year 3209 B.C. to be that of the introduction of the cycle and of the reign of Jemschid, the sovereign to whom the invention of this mode of regulating the calendar is ascribed. We are informed that, with the era of Jesdegird, a new regulation of the solar year was adopted in Persia, and that its commencement was made to coincide with the time when the sun was in the middle of the constellation Pisces[d].

The length of the tropical year, or the interval between two successive returns of the sun to the same equinoctial point, is now known to have been, during the existence of the Egyptian monarchy, less than 365¼ days by about eleven minutes which, in about 130 years, make one day, and the Egyptians, by adding one day at the end of every four years, to their original year of 365 days, rendered their civil year too long, so that at the end

[a] Historia religionis vet. Persarum, cap. 17

[b] Ibid. cap 14

[c] Astr. Ancienne Eclairciss. Liv. IV. sect. 2.

[d] Hyde, cap. 15.

of 130 such years from any epoch, there had in reality elapsed one day more than 130 tropical years; and, as the observations of the times of the equinoxes by the gnomon, or otherwise, were probably, uncertain to half a day only, it may be supposed that in about 300 years, at most, the error of their calendar would become sensible, being, in fact, more than two days. It is also known that the length of the sidereal year, or the interval between two successive returns of the sun to the same fixed star, exceeds 365¼ days by a little more than nine minutes, and these, in about 150 years, make up one day, but the length of the sidereal year being by the Egyptians determined, only by the heliacal risings of stars, and M. Biot having proved that between the years 2000 and 3000 B.C. the interval between two consecutive heliacal risings of a star was 365¼ days, or exactly the length assigned by that people to their tropical year; it is evident that they could not have been aware of any greater error in their calendar than that which we have found above: and, if we are to give them credit for so much attention in comparing their measures of time, we may suppose that the heliacal rising of any star would, to them, appear to take place every year later than in that preceding it, as well with respect to the civil as to the tropical reckoning, or that the equinoctial point would appear to retrograde towards the sun, so that the latter would seem to arrive at the equinoctial point earlier, with respect to the civil as well as the sidereal reckoning: and, taking the sun's movement in longitude at one degree daily, it might appear that the equinoctial points had retrograded with respect to the stars, at the rate of about two degrees in 300 years, or about twenty-four seconds of a degree yearly. But subsequently to the year 1000 B.C., the difference between the interval of two heliacal risings of a star and the period of 365¼ days became perceptible, being equal to about one day in 300 years, and, in that age, the equinoctial points may have appeared to retrograde, from the two differences, about one degree in 100 years, or thirty-six seconds of a degree annually. It is conceivable, therefore, that this retrogradation, as Albategnius and other Arabian writers have asserted, may have been suspected by the Chaldeans and Egyptians, but the want of precision in the observations must

have prevented either people from arriving at an accurate knowledge of its amount. An uncertainty of half a day, in the time of one of the two phenomena observed at an interval of 300 years, would render the determination erroneous by six seconds; and the Greek astronomers varied, in the value they assigned to the retrogradation, between thirty-six and sixty seconds.

The seasons chosen by different people among the ancients for the commencement of the year were different, and seem to have been regulated by rural operations and local circumstances rather than by astronomical phenomena: we have seen that, in Egypt, the beginning of the sacred year was variable, and that of the canicular or agricultural year was fixed either to the day of the summer-solstice or to the time of sowing corn. According to Censorinus[a], some nations reckoned the beginning of the year from the new sun, that is from the winter-solstice; many from the vernal or from the autumnal equinox; some from the [heliacal] rising of the Pleiades and others from their setting: he does not say in which of the four seasons of the year the rising or setting of the Pleiades was supposed to have taken place, and M. Bailly gratuitously assumes that there might be some nations which began the year when that cluster of stars so rose at the time of the vernal equinox, a circumstance which would indicate an age as early as 3900 years B.C., but it is much more probable that the commencement of the year was connected with the rising of the Pleiades in one of the two following ways, either what was denominated the beginning of the year was only meant to signify the time of harvest, which, according to the precepts of Hesiod above quoted, was regulated by that phenomenon, or the nations alluded to pursued a course similar to that which was till lately adopted by the natives of the islands in the South Seas. "The two seasons of the year" says Mr. Ellis[b] "were, among the Tahitians, divided by the Pleiades, the first, called *Matarii i nia, the Pleiades above;* commenced when, in the evening, those stars appeared on, or near the horizon and continued while, after sun-set, they were seen above it. The other season, called *Matarii i raro, the Pleiades below,* commenced when, at sun-set, the stars ceased to be visible, and

[a] De Die Natali, cap. 17.

[b] Polynesian Researches, vol. I. chap IV.

continued till, in the evening, they again appeared above the horizon: in either of the cases above supposed the opinion of Bailly falls to the ground. The civil year was, by the Greeks, made to commence with the autumnal, and by the Romans, before the time of Numa, with the vernal equinox

Syncellus, and Eusebius, of whom we have above spoken, quote from the works of the Chaldean Berosus three distinct cycles under the denominations of Sossos, Neros and Saros, which are said to consist, respectively, of 60 years, 600 years and 3600 years; besides which it is added that 120 sari form the great planetary year or cycle. Josephus also, who perhaps drew some of his notions from the works of Berosus, mentions [a], a period of 600 years which he calls the great year and which, he pretends, was discovered by the patriarchs, to whom he says God granted very long life in order that they might be enabled to gain a competent knowledge of geometry and astronomy. The age in which this Berosus lived is uncertain, and it appears that there were at least two persons of that name, one is said, by Seneca, to have been a minister of Belus, king of Assyria; another was contemporary with Nabonassar, or with Alexander the Great; and this last, or, it may be, a third, is described by Vitruvius as an itinerant lecturer in philosophy who finally settled at Cos.

Whether the years of the Chaldean cycles are to be considered as solar or lunar, or even as days, or whether those cycles relate to the movements of the planets, can only be surmised, nor is there any proof that all the periods are of an astronomical nature; but, according to Sir William Drummond [b], the word Saros is derived from the Chaldean word *Sar* signifying rotundity and, also, the moon; whence it has been supposed to denote the lunar cycle of 223 months, or eighteen solar years of which we shall speak hereafter. What is usually denominated the planetary year is the period comprehended between two conjunctions of the sun, moon and planets in a particular part of the heavens, like that which Cicero, in his treatise *De Natura Deorum* calls the great Platonic year, and, like the "*magnus sæculorum ordo*" mentioned by Virgil in the fourth eclogue of

[a] Antiq. Lib. I. cap 3.

[b] Origines, Book I. Chap. V.

the Bucolics. Now if this conjunction were supposed to possess the precise character attached by astronomers, at present, to a conjunction; which is that the planets should have the same, or very nearly the same, longitude, the cycle would be of immense duration; and some persons imbued with this opinion have supposed that a period of 49,000 years; others, that one of 23,760 years was referred to: but this kind of conjunction does not seem to have been intended by the ancients. It is evident, however, that no correct knowledge can be obtained of the duration of such periods while we are ignorant of the extent of the heavens within which the planets were supposed to be contained when they were considered to be in conjunction; for this may have been a whole sign, or even a quadrant of the zodiac; a difference which would alter in a vast degree the extent of the cycle. Proclus, in his treatise *De Sphæra* [a], ascribes to the Chaldeans the opinion that, in the great planetary period, whatever it may be, the universe experiences an entire revolution; that the commencement of the world coincided with that of the period, and that its destruction would take place when the period should be completed, after which they supposed that all things would return to their previous state. Aristotle speaking of this period, which he designates a great year, observes that its winter is accompanied by a *Cataclysmos*, or deluge, and its summer, by an *Ecpyrosis*, or conflagration of the world. The superstition of the ancients may be conceived capable of originating such notions; we meet with them in the chronology of the Hindus, and there are traces of their existence even among the inhabitants of enlightened Europe.

Scaliger considers the Saros to be the same as the Dodecaëteris, or period of twelve years which, as Censorinus observes [b], the Genethliaci call the Chaldean year, a period not depending on the course of the sun or moon but on observations relating to the supposed returns of good and bad harvests, or of periods of health and sickness: and he supposes the planetary year to be equal to 1440 solar years, being the product of that period into a sæculum, or age, which he makes equal to 120 years. But Le Gentil, considering all the Chaldean cycles to relate to the con-

[a] Cap. 1. [b] De Die Natali, cap. 15.

junctions of the sun and moon, has attempted to explain their values on this hypothesis; and, admitting that the Chaldeans had assigned to the solar year and the lunar month the lengths he assumes, he shews that 60 years would contain $742\frac{1}{10}$ lunations, and, ten times this period, or 600 years, would contain 7421 lunations exactly, and thus might be formed the Neros of Berosus, or the Great Year of Josephus. It is impossible, however, to know what proportion, according to the Chaldeans, the solar years and the lunar years bore to each other; therefore little confidence can be placed in this ingenious explanation: it, moreover, leaves the Saros entirely unaccounted for and, in fact, Le Gentil admits that it is quite inexplicable.

But when the astronomical tables of the Hindus were received in Europe efforts were made to explain the ancient periods from the elements those tables afforded, and M. Bailly has[a], particularly, laboured to draw from those of Chrisnabouram a probable solution of the question concerning the Chaldean Neros; for this purpose he calculates, by them, the mean motions of the sun and moon with respect to the equinox, in 600 tropical years, the length of which he takes from the same tables, and, allowing for the movement of the equinoctial points in that time according to the value assigned to this element by the Hindus, he finds that a certain number of revolutions of the moon are accomplished in the 600 revolutions of the sun with an excess of 3 minutes only; whence, he observes, one of two things must be inferred, either that this cycle has been formed from the tables, or that the latter have been computed from the cycle. The coincidence is certainly remarkable, and may prove that the period has been formed by a comparison of the mean motions of the sun and moon; but, while the antiquity of the Hindu tables is liable to so much uncertainty, most persons will be inclined to embrace the opinion that the last inference drawn by M. Bailly has the best foundation in probability.

In the same work[b], the learned author observes that the period of 3600 years, the Saros of Berosus, is often referred to in the Hindu astronomy, and he conceives it to have arisen from the discovery that, reckoning from the commencement of the age

[a] Astron. Indienne, Disc. prelim. page 143. [b] Chap. X. sect. 15—19.

Cali-Yuga, that number of years must elapse before the origin of the Hindu zodiac would coincide with the equinoctial point.

The cycle of 60 years is in general use in the eastern chronology, and Bailly conceives that it may have originated in the observed conjunctions of Jupiter and Saturn, which occur every twenty years in parts of the zodiac distant from each other 120 degrees in longitude; that is in those signs which constitute one of the astrological trigons: hence three conjunctions, which take place in 60 years, will have been accomplished in all the points of one trigon; and, as this division of the zodiac appears to have been very ancient in the East, the opinion is not destitute of probability. Some, however, have imagined that the Sosses of Berosus was a period of 60 days, or two synodical revolutions of the moon nearly, the use of which cycle, according to Censorinus [a], prevailed in Egypt, and is, we know, still retained in India and China.

Besides the cycles abovementioned, three, which relate to the superior planets only, are mentioned by Achilles Tatius [b]; that writer, after describing the periodical revolutions of those planets in their orbits, states that Saturn has a period of 350,635 years which, he says, is called the great year; Jupiter, one of 170,620 years, and Mars, one of 120,000 years, at the end of which times they return to the same, he does not say what, point. Bailly, in his effort to explain every thing, imagines that these periods might have been formed by multiplying the times of the supposed revolutions of the aphelia of the planets by those of the periodical revolutions of the planets themselves; but the products arising from the multiplication of the values now assigned to those times give periods which differ very much from those mentioned by Tatius, and there is sufficient reason to believe that, in the days of that writer, the movements of the planets' aphelia were not even suspected. Censorinus speaks of a Chaldean period of twelve years which, he says, was supposed to bring on, in regular order, years of famine and sickness: and those who have attempted to shew from what phenomenon the number was derived have imagined that it related to one of those presented by the planet Jupiter which, at the end of

[a] De Die Natali, cap. 21. [b] Isagoge, cap. XVIII. in Petav. Uranolog.

twelve years returns nearly to the same configuration with respect to the earth and sun. The period which includes nine conjunctions of Jupiter and Saturn brings those planets to such situations that, if the first conjunction should occur at the beginning of the sign Aries, the last will occur at the end of the same sign, and this has been supposed by Bailly to be the origin of the period of 180 years which now is, and, probably, from ancient times has been in use in some parts of Asia To conclude, we may observe that Bailly has enumerated[a] about eighteen different cycles besides those ascribed to the Chaldeans and Egyptians; some of them are apparently luni-solar, while others seem to depend upon the supposed movements of the equinoxes, and he quotes from Censorinus a remark that there was a Great Year of infinite length; whence he infers that some among the ancients had arrived at a knowledge of the incommensurability of the periodical movements of the celestial bodies.

Great importance was, by the ancients, attached to the knowledge of those cycles which in the Greek astronomy were called *Exeligma*, and which constitute integral periods of the revolutions of the celestial bodies; and it is evident that they must have afforded the only means then known of computing the returns of the phenomena to which they related. In the modern astronomy they are quite abandoned, it being more accurate as well as more independent, to determine the mean motions of the celestial bodies by a comparison of their situations at periods remote from each other. These mean movements for years, months, days, &c being reduced to tables, are easily taken from thence, and the corrected places of the celestial bodies are found by applying the variations to which the movements are subject; such variations have been deduced from the physical causes affecting the movements; and the formulæ investigated for the purpose of expressing them have also been reduced to tables subsidiary to those which give the mean places and movements. The formulæ and the tables computed from them are corrected from time to time, as observations are multiplied and become more perfect, and no correction of an empirical nature is now admitted.

[a] Astron. Ancienne Eclairciss. lib. VIII. sect. 15.

Hitherto we have only considered the most simple observations that might have been made and the most obvious deductions from them, and it will be readily acknowledged that such observations and deductions do not surpass the means in the power of either the Chaldeans or Egyptians, in the ages which preceded that of the Greek astronomy. But Geminus[a], who is thought to have lived about one hundred years before Christ, ascribes to the former people observations and deductions of kinds superior to those of which we have before spoken, and such as indicate considerable advances in the formation of a theory of the lunar motions. If what he alleges be correct, they must have ascertained the variable velocities of the sun and moon, the situations of the apsides and nodes of the moon's orbit and the periods of her revolution with relation to those points. They discovered, he says, that, in eighteen years, or $6585\frac{1}{3}$ days, the moon had made 223 complete revolutions with respect to the sun; 241 revolutions and $10\frac{2}{3}$ degrees with respect to the fixed stars; 239 restitutions of anomaly, or revolutions with respect to the apsides or points of her greatest and least velocities, and 242 restitutions of latitude, or revolutions with respect to her nodes; but he adds that, in order to obtain an entire number of days, they tripled all the above numbers; and thus formed a new period consisting of 19,756 days, or about fifty-four years, in which, consequently, the moon would make $723\frac{4}{45}$ sidereal revolutions; 669 revolutions with respect to the sun; 717 revolutions with respect to the apsides, and 726 revolutions with respect to her nodes. The truth probably is, that the Greeks determined all or some of these periods by comparing the times and phenomena of the eclipses observed by the Chaldeans or Egyptians with such as were made, in later times, by astronomers of their own nation: but, as the more ancient people could have had no other object in view, in making their catalogues of celestial phenomena, than to afford the means of ascertaining such periods; it would be unreasonable to suppose that they did not, themselves, use their observations for a like purpose, though we may grant that the cycles they thus formed were less accurate than those which

[a] De Apparentiis Cœlestibus, cap. de Mensibus.

are above announced. The periods in which the restitutions of the lunar inequalities of motion, in longitude, are found to take place, from the preceding cycles, are as follow: the period of restitution with respect to the fixed stars in 27.321 days; to the sun in 29.531 days; to the moon's apogeum in 27.553 days, and to her node in 27.212 days. And the agreement of these values with those found from the corresponding Hindu cycles, which will be hereafter mentioned, is so remarkable as almost to justify a suspicion that the different people did not make the discovery of the cycles quite independently of each other.

The determination of the mean values of these periods, even without the aid of instruments for ascertaining directly the place of a star or planet with respect to the circles of the sphere, is however, a work of comparative facility; and the method employed by the ancients appears to have been nearly the same as that which is followed by the astronomers of the present time; the only advantage enjoyed by the latter, in this research, consisting in a more accurate knowledge of the actual places of the celestial bodies, and in a diminution of the errors in the lengths of the periods, by being enabled to make comparisons of such places after the lapse of great intervals of time. To ascertain the time of a sidereal revolution of the moon it would only be necessary to observe two successive near appulses of that luminary to some fixed star, which would give an approximate value of that period; then, observing two such appulses distant from each other by many years, since an integral number of such revolutions must have been performed in the interval, if that interval be divided by the approximate value, the nearest integer to the quotient will be the number of revolutions; and, the whole interval being divided by such integer, the new quotient will be the more accurate value of the sidereal revolution.

By a similar process the duration of a synodical revolution of the moon might have been ascertained: for the interval between two consecutive first appearances of the new moon would afford an approximation to the period: and two such observations made at times very distant from each other would give the duration with great accuracy. The two remaining periods must

have been ascertained from the registered eclipses of the moon; and Ptolemy expressly states that the ancient mathematicians, meaning no doubt the Chaldean astronomers, had made the discovery of such periods. The revolution with respect to the node might easily be found from the registered times of two lunar eclipses which are total and central, for, in those circumstances, the moon must be in or near one of her nodes; the interval between two such phenomena, being divided by the duration of a sidereal revolution, as an approximation to that with respect to the nodes, would give the integral number of revolutions of the latter kind in the interval, and hence might be obtained the correct duration of a revolution from one node to the same. If the place of the moon in the zodiac, at the time of such an eclipse, was determined by her appulse to some known fixed star, the perceptible changes of her situation with respect to the same star at the times of the succeeding eclipses, the moon being then also near her node, would shew that the node retrograded, or moved from east to west in the heavens; and, as, at the end of about eighteen years, a central eclipse would again be found to take place at the same distance as at first from the same fixed star, it might be concluded that a revolution of the moon's nodes is accomplished in that time. Lastly, if in the registers of eclipses there be found two which are equal in magnitude and duration, the velocity of the moon being at those times, consequently, equal; it will follow that the moon must, at both times, have been either in the line of the apsides, or at equal distances from the apogeum. Therefore the interval of time divided, as before, by the approximate time of one revolution will give the integral number of revolutions with respect to the apogeum in that interval; and, from thence, may be obtained the more correct time of such revolution. The different positions of the moon, with respect to the fixed stars, when she is in the apsides of her orbit might have shewn that those points were not immoveable in space, and might indicate their velocity and the direction of their motion; and though we have no direct proof of it, there seems no reason to refuse, to the more ancient Chaldeans or Egyptians, some knowledge of their periodical revolutions. That the Chaldeans

were aware of the inequality of the moon's motion is sufficiently evident since, according to Ptolemy, they held, though we know not in what age, an opinion that, in passing from apogeo to perigeo, her movement was uniformly accelerated as much as eighteen minutes daily; and in returning from the latter to the former point, it was retarded in the like manner: and though they were wrong in supposing this acceleration and retardation to be uniform, yet the discovery of a variation in the velocity, as is observed by La Place [a], is a proof of their sagacity, and is the earliest fact of the kind of which we have any knowledge.

An argument in support of the notion that astronomy was cultivated in the East long antecedently to the origin of the Chaldean and Egyptian monarchies has been drawn from the extent of the cycles in which the lunar inequalities are compensated: it is alleged that, in order to discover by the recurrence of like eclipses the time of a compensation, a greater number of years are required than are supposed to have elapsed since the epoch of that origin; and hence it is concluded that the first observations must have been made in times much more remote. In proof of this allegation it is remarked that, besides the length of the interval between the nearest recurrences of the eclipses by which the compensation of an inequality is determined, the regular returns of the eclipses themselves so often escape observation, by those taking place below the horizon of the spectator which, at a previous return, may have occurred above it, that many periods must pass over before the length of one could be ascertained. M. Delambre observes [b] that not half the eclipses which take place in any one period would be visible, and Cassini, in the Mémoires de l'Academie des Sciences [c], goes so far as to say that, among all the eclipses which have happened within the last 2500 years, there are no two of the same kind distant from each other by so great an interval as one of the periods referred to by Hipparchus, from which circumstances it may seem quite natural to infer that many ages must have elapsed, and a very great number of observations must have been made to enable the astronomer, by

[a] Exposition du système du monde. Note II.

[b] Hist. de l'Astron. au 18[eme] siecle, page 409.

[c] Tom. VIII.

several coincidences, to conclude that the periods are constant. The remarks we are about to make will, however, in our opinion, afford ground to believe that the number of years requisite to determine the periods of the lunar inequalities is not, necessarily, so great as might at first be supposed.

Delambre seems to consider that the recurrence of one eclipse only, at the lunar apogeum or node, or at the same distance from either, is observed within one period of restitution, but it must be remembered that all the eclipses visible within two periods of the restitution of one kind of inequality amount to a considerable number; so that among them, though the returns of some may not, those of others will, be found; and these are sufficient to afford an approximate knowledge of the period, which period might be afterwards verified or corrected by the observations of similar eclipses at longer intervals; or extended, as was done by the Greeks and Hindus, by the simple process of taking equimultiples of the number of restitutions and of the time in which that number was accomplished. We must remark, moreover, that the phenomena of two like eclipses need not agree with the utmost precision, neither indeed is it possible that they should; but this agreement is supposed by Cassini, when he says that no two like eclipses are to be found in registers kept during 2500 years: in fact, however, a near approximation to similarity was sufficient for the ancients, who, by taking a mean of a multitude of observations, procured a tolerably accurate knowledge of any period through the compensations of the errors; and of eclipses nearly similar to each other there would be many in a much smaller number of years. Let us add that the ancients enjoyed the advantage of a fine sky, and that among them a class of men was almost wholly devoted to the contemplation of the heavens, from which circumstances it may be inferred that, in a given time, they must have made many more observations of that nature than have been made since the days of Ptolemy; when, till lately, the practice of astronomy was less constantly cultivated than before: even now, many such phenomena are lost to us by the vapours of our atmosphere which too frequently conceal the celestial bodies from our view

It is conceivable, therefore, that the two thousand years which had elapsed between the Deluge and the age of Aristotle, and the longer interval between that great event and the time of Hipparchus, may have sufficed to obtain the number of observations necessary to determine the periods alluded to by the former, and employed by the latter astronomer: it is even reasonable to believe that the series of Chaldean observations, extending through 1903 years, which are said to have been transmitted to Aristotle by his friend Callimachus, consisted of eclipses, and occultations of stars or planets by the moon, and that the former are those by which Hipparchus determined the elements of the lunar orbit, it is probable also that, from the latter, were obtained the periods, relating to the movements of the planets, which are stated in the works of Ptolemy.

CHAPTER VII.

ASTRONOMICAL MONUMENTS OF THE ANCIENTS.

Notices concerning the Chaldean and Egyptian Hermes.—Alleged superiority of the Egyptian Astronomy.—Sculptured representations of the heavens.—The sculptured planisphere in the Temple of Isis at Denderah.—Its supposed epoch.—The rectilinear zodiac in the same temple.—Sculptured zodiacs at Esneh and Dehr.—Opinions of M. Dupuis concerning the signification of the zodaical constellations.—The positions of the leading signs in the Egyptian zodiacs.—Hindu and Roman zodiacs.—Notices concerning the Persian astronomy in the Zend-Avesta.—Hypothesis of Dr. Stukely concerning the Druidical monuments in Britain.

It appears that between the time of Ptolemy and the epoch of the revival of learning in Europe, if not at an earlier period, several books, either genuine or apocryphal, must have been in existence, in which mention was made of the Chaldean or Egyptian learning; for such are frequently alluded to by the writers of the middle ages, and a certain Hermes, or Mercurius Trismegistus, is occasionally quoted as a personage living in very remote times, and either as an observer of the heavens or the author of certain astronomical sculptures or writings. Jamblichus relates[a], on the authority of Seleucus and Manetho, that he wrote, concerning the theology and astronomy of the Egyptians, a number of books equal to the years during which the thirty dynasties of kings are said to have reigned over that people; an idle fable from which we can only infer that many works relating to those subjects had been written by different persons and were ascribed to Hermes, just as the actions of more than one of the ancient heroes were, by the Greeks, attributed to Hercules. This is so much the more probable as we know that the priests of old were frequently denominated from the deity to whose service they were consecrated[b]; and, consequently, there may have been many individuals, priests of Mercury, bearing that appellation. It is, also, easy to conceive that the name of Hermes may have been assumed by different

[a] De Mysteriis Ægyptiorum, Sect. VIII. cap. I. in Fabricii Biblioth. Græc. Lib. I. cap. II.

[b] Bryant's Analysis of Ancient Mythology.

persons merely to procure a sanction for their opinions in philosophy by pretending that they were those of a celebrated ancient: such artifices are generally found to be successful, because men can hardly avoid being strongly prejudiced in favour of doctrines supposed to have descended from antiquity; which, on that account, they regard with veneration, and accept as the precepts of a parent.

The Hermes mentioned by Manetho was, probably, the first of the name, he is pretended to have been an Egyptian, contemporary with, and the minister of Osiris who lived about 1800 years Before Christ: he is also supposed to have been the Buddha of the Hindus, but on no better foundation than that the fourth day of the week, among the latter people, is dedicated to that deity as the fourth day of the Egyptian week was to Thoth or Hermes, and that both Hindus and Egyptians marked that day by the symbol of Mercury Abulpharagius[a] names a Chaldean Hermes who, he says, lived some years after the Deluge, and Alpetragius mentions one to whom he ascribes the pretended discovery that the stars have a motion, real or apparent, which is alternately direct and retrograde. This opinion of two opposite movements in what are called the fixed stars is known to have been entertained in the first century of the Christian era, and if the Hermes here spoken of be not a fictitious personage, he very probably lived about that time. In the Philosophical Transactions for 1694, the longitude of Aldebaran is alleged to have been observed by Hermes, and, from the position assigned to the star, it would appear that the observation was made above 3000 years Before Christ but, as no authority is given for his assertion by the writer of the article, it is impossible to form any opinion of its truth or falsehood.

One of the Hermes appears to have been the author of a work which was esteemed of high importance by the priests of Egypt, and, probably, contained the rules for determining the times of celebrating their religious festivals · this we learn from Clemens Alexandrinus, who lived in the second century of our era, and who, in describing the persons attending in the processions made in honour of Isis, states[b] that one of them, de-

[a] Historia Dynastiarum. [b] Stromata, Lib. VI.

nominated the Scribe, was acquainted with the hieroglyphics relative to cosmography and geography, and to the courses of the sun, moon, and planets; and that another, named the Horoscope, was skilled in the four books of Hermes on astrology and astronomy; the first of which, he observes, treats of the order and disposition of the universe and of the five planets; the second, of the conjunctions of the sun and moon, and the two others, of the risings of the stars. And to the same Hermes or to some writer who, subsequently, bore his name, the Arabian astronomer Ibn Jounis has ascribed a treatise on shadows, probably meaning those of a gnomon, which were so long and generally used to determine the times of the equinoxes and solstices. We regret the impossibility of fixing the age in which any one of these philosophers flourished, and are compelled to observe in conclusion that the subject is involved in impenetrable obscurity.

The science of the Egyptians was considered, by Herodotus, superior to that of any other Eastern people of his time, but he only alleges two circumstances in support of the opinion; one of which is the remarkable and, seemingly, irrational story related to him in a conversation with some of the priests, that in 11,340 years the sun had four times changed the place of his rising, having twice risen where, now, he sets[a], meaning, probably, that there had twice occurred a rising in the west alternately with one in the east: and the other is the discovery that the year consists of 365 days. The first of these, which is, also, alluded to by Pomponius Mela[b], though the author assigns to the period 13,000 years, may, if it have any meaning, admit of explanation in two different ways. M. Dupuis, who labours with all his might to support the opinion that the Egyptian astronomy had its origin in a most remote antiquity, takes for real the long period which the recital of Herodotus would appear to give to the existence of the monarchy; and, assuming that the period is nearly equal to half of that in which the fixed stars seem to make a revolution in longitude by the retrogradation of the equinoctial points, though in the account given by Herodotus

[a] Euterpe, cap. 142. [b] Pomp. Mela, Lib. I. Ægypt

it differs from it above sixteen hundred years, he supposes[a] the relation to be founded on the change which, by that half revolution, is produced in the positions of the stars with respect to the colures. These circles dividing the zodiac into four quadrants, denominated by some ancient writers, the east, south, west, and north, the stars which, at any epoch, occupy the eastern division, will, in the course of half a revolution, occupy the western division, and so on, consequently the sun which, at the first period, rises and sets with certain stars, will, at the second, rise and set with those which are diametrically opposite. and Dupuis conceives that the Egyptian priests may have intended to express this circumstance, in their enigmatical language, by saying the sun had reversed the place of his rising and setting

A very different interpretation of the words of Herodotus, and one which to most persons will doubtless appear far more reasonable, has been lately offered by Dr Renwick in a letter to Captain Sabine, which was published in the Journal of the Royal Institution for May 1831. This is founded on the supposition that the period referred to by Herodotus or Mela signifies the duration of one Sothaic cycle and half a cycle; that is 2190 years: Dr. R. observes that, at the commencement of the cycle, the sun would be in the constellation Leo at the time of the heliacal rising of Sirius, that, after 730 sacred years, he would, on the same day of the [vague] year, be in that part of the zodiac which is in opposition to Leo; and, consequently, would rise with a constellation which, at the beginning of the period, was setting at the time of his rising; at the end of the cycle he would rise and set with Sirius as at first: and, after another 730 years, he would again rise with the opposite constellation. The only difficulty in the way of this explanation is the substitution of 2190 years for 11,340 or 13,000; but, if we suppose the latter to have been years of two months each, the agreement would be sufficiently close. Herodotus states that the period included between those pretended changes of the sun's place of rising extended from the reign of the first king of Egypt to the time of Sethos, a priest of Vulcan: now the latter is

[a] Mémoire du Zodiaque, p. 37.

said to have lived about the year 700 B. C., and this fact would place the reign of the first king of Egypt in the year 2890 B.C. an epoch which is, probably, rather too remote.

The observation of Herodotus, that the year discovered by the Egyptians consisted of 365 days, must be understood to imply, merely, that these people were the first to employ the *annus vagus* for religious purposes, and not that, in the time of the Greek historian, they were unacquainted with the fact that an additional quarter of a day was included in the length of their agricultural or tropical year; since, as we have already shewn, there is sufficient reason to believe that the latter measure of time had been much more anciently in use among them. Of the observations made on the celestial bodies by the Egyptians, not one has been preserved unless we consider as such the seven heliacal risings of Sirius ascribed to them by Ptolemy in his treatise on the calendar: the first of which, if the account may be credited, took place four days after the summer solstice, and, consequently, about the year 1940 Before Christ: even the notices of such eclipses of the sun or moon as we cannot doubt they observed either were not in existence in the time of Ptolemy or were overlooked by that astronomer, since he has had recourse to those of the Chaldeans in order to obtain data for his investigations concerning the orbits of those luminaries. La Place is inclined to think[a] that the priests of Egypt might have been jealous of the school at Alexandria, which had been founded by the Ptolemies; and therefore, withheld from the astronomers of that establishment whatever knowledge they might have previously acquired while Delambre shrewdly remarks that, as men seldom conceal what would enhance their reputation, it is very probable that the priests had nothing of importance to communicate, and that they concealed their ignorance under an affected reserve. But neither of these opinions can be entirely just, for the Egyptians could not have observed the heavens during so many ages without making many discoveries, nor could Ptolemy have been ignorant of the contents of such works on astronomy as those ascribed to Hermes, which appear to have been generally known about his time; we must, therefore,

[a] Precis de l'histoire de l'Astronomie, Chap. I.

ascribe his silence respecting the science of the Egyptians to some other cause, which, perhaps, may have been, that the observations of more ancient date than those he employed were not accompanied by details sufficiently precise to serve the purpose he had in view.

Some of the sacred edifices of the Egyptians, Hindus and Romans are found to exhibit striking proofs of the importance which these several people attached to the science of astronomy, in the representations of the heavens sculptured on their ceilings. Either the figures which designate the constellations were considered fit subjects for a display of taste in one of the fine arts, and the idea of applying them in such situations arose from a supposed correspondence of the ceiling of an apartment with the visible surface of the vault of heaven, or, as the celestial bodies were objects of adoration in the East, such representations were considered of use in exciting the devotion of the people: whatever may have been the reason of this remarkable practice, it probably originated in Egypt where, alone, the existing specimens bear, in their execution, marks of an attention to scientific principles. Though the precise age of these Egyptian sculptures is very doubtful, and though we have reason to believe that they are not so ancient as the disposition of the figures in them seems to indicate, yet that similar works were executed, in very early times, in that country, is highly probable from the account given by Diodorus Siculus of a *Golden Circle* in the tomb of Osymandius, which, he observes, is the most magnificent of all the sepulchres of the kings of Egypt. The circle, he says[a], was one cubit thick, or broad, and 365 cubits in circumference. it was divided according to the number of the days of the year and was inscribed with the subjects professed by the Egyptian astronomers; in which it has such a marked resemblance with one of the representations about to be described that little doubt can be entertained of its nature, though some late astronomers seem to have taken it for an instrument used in making celestial observations. Diodorus adds that the circle was reputed to have been taken away by Cambyses when he conquered the country.

[a] Biblioth. Hist. Lib. I. sect 46.

The most important of the sculptures lately discovered in Egypt represents, apparently, the whole of the visible heavens on a plane surface, within a circular margin; and was executed on the ceiling of an upper apartment in the Temple of Isis at Denderah. On the same level, and on the opposite side of the building, is another apartment also decorated with astronomical emblems, but having no roof, and seeming, as M. Letronne observes, to have been intended as an observatory from whence the sculpture in the before-mentioned apartment might be verified by an actual inspection of the heavens. By M. M. Jollois and De Villiers, the authors of the *Recherches sur les Bas-reliefs Astronomiques des Egyptiens*, in the Mémoires de l'Institut [a], the planisphere is supposed to be a projection of the northern celestial hemisphere on the plane of the equator; the twelve zodiacal constellations are easily distinguished on it by their resemblance to those on a common globe, and follow each other in the order at present assigned to them except that Cancer, instead of coming between Gemini and Leo, is placed above the latter towards the centre of the sculpture: this displacement has caused the figure to be taken for the mythological scarabeus or beetle, the symbol of deity; but as, here and elsewhere, it has eight feet while the beetle has only six, there can be no doubt that it represents a zodiacal constellation. All these figures are contained within an annular band, whose centre is in a line drawn through that of the planisphere, or the pole of the world, and through both Cancer and Leo, which, of all the zodiacal constellations, are those nearest to that pole. It would seem, therefore, that this line must be the projection of the solstitial colure; and, consequently, that the planisphere represents the state of the heavens at the time when the summer solstice was either at the commencement of Leo or at the end of Cancer. But M. Biot, in his *Mémoire sur le Zodiac de Denderah*, does not allow the planisphere to be a stereographical projection of the heavens, and he alleges, in opposition to that opinion, that the ecliptic, a great circle of the sphere, lies wholly within the primitive, or circle bounding the representation, which is con-

[a] Sect. I. Chap. 2.

trary to the principles of that kind of projection: the ingenious authors of the *Recherches* admit, also, the inaccuracy of the construction, because a circle described about the centre of the sculpture, which is the pole of the world, passes through the centre, or pole, of the ecliptic and touches, at a point diametrically opposite, the interior circumference of the annulus occupied by the zodiacal figures, whereas in the heavens, or in any such projection of the sphere as is here attempted, one of these points ought to be twice as far as the other from the pole of the world.

The opinion proposed by Biot is that the sculpture represents a development of the whole sphere, formed by assuming a certain point as the north pole of the equator and drawing radii, from that point as a centre, equal in length to half the circumference of the sphere, so that the circumference of the exterior bounding circle, or primitive, may be considered as the pole opposite to that in the centre of the planisphere. In support of this hypothesis Biot shews that if the mutual distances of the four stars Arcturus, Antares, Fomalhaut and β Pegasi be determined trigonometrically on the monument, by means of their measured polar distances and differences of right ascension, and compared with the distances of the same stars, found from their known longitudes and latitudes, the differences between the results of the computations for any two of the stars will not exceed 2° 41′, and a nearer correspondence could hardly be expected, besides which, it may be observed that this kind of development would most naturally present itself to the mind of any one who sought to represent, on a plane, the visible concave surface of a sphere, before the mathematical theory of projections was invented. To determine the epoch of this interesting monument, the author of the hypothesis calculates the position of its pole by the computed distance between two of the four principal stars above-mentioned and their distances from the centre, found by measurement; and he finds the pole to be midway between the stars β Ursæ Minoris and κ Draconis, a situation which indicates the year 716 Before Christ. The probability of the epoch thus determined appears to be strengthened by the fact that near the place where, by calculation, Biot finds the equinoctial colure, is

a small Harpocrates sitting on a lotus leaf, and within this figure he finds the place of α Piscium which, about the year 700 Before Christ, rose with the vernal equinox, and may have served as an indication of the time when that point was in the horizon, a circumstance, of some importance in the ancient astronomy and, therefore, very likely to have prompted the artist to mark that point of the heavens by some appropriate emblem. Plutarch, in his treatise *De Iside et Osiride*, states that the Egyptians represented the return of the sun towards the summer solstice by a child issuing from a lotus plant, and this also may be considered as an argument in favour of the opinion that the above-mentioned figure was intended to represent the place of the equinoctial point The position of Sirius is found, by computation, to be in the stem of a lotus plant on the top of which is a hawk, the symbol of the deity; and this stem is in the direction of that diameter of the sculpture which is parallel to the longitudinal axis of the temple and on the northern side of the centre. No star is sculptured on this plant but there is one very near it between the horns of a cow, the emblem of Isis, to whom Sirius was consecrated, and hence it is supposed, by Biot, that this figure was intended as the representation of the star Sirius, or of the constellation Canis Major. The head of the cow is near the feet of that figure which he considers as the emblem of Cancer; and he concludes that this disposition of the figures has some allusion to the simultaneous heliacal rising of Sirius and the stars near Cancer, which took place in the age he has assigned as the epoch of the monument. The line of the solstices is placed accurately in the direction of the meridian, the summer solstice being towards the north: and a line drawn through the centre of the planisphere, parallel to the length of the temple, is inclined to the meridian in an angle of about 17° eastward of north. The heads of all the figures are in the direction of the diurnal motion of the heavens, and the figures follow each other in the order of the signs.

The displacement of Cancer and its introduction above Leo may have been intended to shew that, at the epoch of the monument, the summer solstice was on the confines of both those constellations; and the hawk-headed human figure situated

between Gemini and Leo perhaps expressed some quality of Cancer, on which account it may have been made to occupy the place of the constellation itself. Sundry other variations are found between the figures sculptured on the Egyptian planisphere and the constellations we have received from the Greeks, which Biot endeavours to reconcile by supposing, either that the emblematic figures have been occasionally substituted for the constellations to which they refer, or that an attempt has been made to express the positions assumed by the latter with respect to the meridian and horizon: thus he imagines Ursa Major to be figured by the emblem of Typhon, and the Ship of Argos, or rather of Osiris, by two human figures with birds' heads and certain emblems; for under the feet of Sagittarius, and diametrically opposite to them, in the sculpture, is the figure of a ship accompanied by the like emblems; and, hence, he considers that these figures have a relation to each other, which he explains by the fact that, at the time of the supposed epoch of the monument, Sagittarius and the Ship came on the meridian together, the former as much above the horizon as the latter was below it, so that the Ship must have appeared to be under the feet of Sagittarius. Groups of stars towards the circumference of the planisphere, and in the direction of a line drawn through its centre and the true places of the Pleiades and Hyades, are supposed, by Biot, to represent those clusters. The position of this temple seems to have been fixed on by design, for its south and north faces are directed to a point situated about 17° 30′ southward of the east point of the horizon, which, about the year 700 Before Christ, is precisely the point where Sirius must have appeared to rise.

In the ceiling of the portico of the temple at Denderah is a representation of the signs of the zodiac in two rectangular bands parallel, and nearly contiguous to the side wall: on the right hand, beginning at the front of the portico, is Cancer, next follow in succession towards the naos of the temple, Leo, Virgo, Libra, Scorpio, Sagittarius and Capricornus; then, on the left hand, proceeding from the naos towards the front of the portico, are the remaining five signs. Between Pisces and Aries is the figure of a hog which probably is not to be considered as one of

the constellations, but rather as an emblem of the season at which this kind of animal was led out to seek its food in the fields; and parallel to each of the two bands is another consisting of figures, in boats, which represent the southern extra zodiacal constellations. The figure of Cancer is placed below the line of the other six signs, and in the place which it should have occupied is a head of Isis enveloped in the solar rays, which M. Fourrier supposes to indicate that, at the epoch of the monument, Sirius rose heliacally when the sun was in Cancer. Now about the year 2500 Before Christ, Sirius rose heliacally in Egypt on the day of the summer solstice, when the longitude of the sun exceeded that of Sirius by 48° 30′ and the luminary was in conjunction with Regulus; and about the commencement of our era, the same star rose heliacally eighteen days after the solstice when the longitude of the sun differed from that of Sirius by $31\frac{1}{2}°$, and was nearly the same as that of the star κ Leonis which is now considered as marking the commencement of this constellation or the eastern extremity of Cancer: it follows, therefore, that in all that interval, which comprehends the duration of the Egyptian empire, the sun must have been within the western half of Leo, at the time of the heliacal rising of Sirius, and could not have reached Cancer unless the boundaries of those constellations have been changed since the epoch of the monument: this is not unlikely, but Biot supposes that the artist intended merely to express the simultaneous rising of Sirius with some of the stars of Cancer, which certainly took place within the above-mentioned interval.

Besides the sculptures at Denderah two other representations of the zodiacal signs have been discovered in Egypt, one of which is on the ceiling of the portico in front of a temple at Esneh and the other, on that in front of a small temple at Dehr near the same city. Towards the right hand, on entering the portico at Dehr and beginning with the front, the first sign is Virgo, then follow Libra and the rest, in order, to Aquarius; on the left hand, the first sign next to the naos is Pisces and the last, which is at the front of the portico, is Leo. Over the lion is a twisted serpent which, if intended to represent the sun, may indicate that the luminary was in this constellation at the end of

the year. In this zodiac, as well as in that of the portico at Denderah, the arrangement of the figures is according to the order of the signs in the heavens; Cancer or Leo, in the latter, being the leading constellation, and Virgo, in the other. In the ceiling of the portico of the great temple at Esneh, the zodiacal signs are in two parallel and nearly contiguous bands, extending between two rows of columns on the left hand side of the portico, on entering. The order of the figures is contrary to that in the other temples, and to the order of the signs in the heavens. A sphinx having a lion's body and a woman's head is the sign nearest to the front of the portico and the constellations follow, in order, towards the naos, those in this band ending with Aquarius; in the other band, the first constellation is Pisces and the others follow in order towards the front of the portico, but after Leo come two human figures with lions' heads, a circumstance which, taken in connection with that of the sphinx in the other band, has given rise to an opinion that the division of the series of signs in the two bands was intended to take place in the middle of Leo; and the opinion is strengthened by the existence of a small scarabeus between Leo and Virgo, denoting, probably, the presence of the sun in the former of these constellations at the commencement of the year.

The principle laid down by Dr. Young in determining the epoch of any monument from the astronomical symbols it may contain, is that those symbols represent the state of the heavens with respect to the season of the year at the epoch sought; and, in applying this principle to the problem concerning the antiquity of the Egyptian zodiacs, Dr. Young first assumes that the place in the heavens occupied by the sun at the commencement of the *annus vagus* retrograded through one sign in about 119 years, or through the whole zodiac in 1424 years, (a period founded on a comparison of the Egyptian, with the sidereal year,) and then, considering that the former began on the day of the autumnal equinox in the year 120 B.C. (130 B.C); it follows that Virgo must have been from that time till the eleventh year B.C. the leading sign of the zodiac, or the sign preceding that in which the sun was on the first day of Thoth, that Libra must have been the leading sign from the year 249 B.C. to 130 B.C. and so

on, reckoning backward: while Leo would have been the leading sign from 11 B.C. to 108 A.C. Cancer, from thence to the year 227 A.C. and so on. If this celebrated and learned antiquary had compared the Egyptian with the tropical year, which would seem to have been a more correct method, the commencement of the *annus vagus* would have retrograded through one sign in about 125 years, and through the ecliptic in 1506 years.

But, according to Dr. Young, if, in the zodiacs of Denderah, we take Leo to be the leading sign, the corresponding epoch of the monument will be between the year 11 B.C. and 108 A.C., or in an age earlier by 1500 years, or by some multiple of that number of years. And, in the zodiac at Esneh, if we take Pisces to be the leading sign, the epoch would be about the year 800 B.C.; if we take Virgo, it will be the century immediately preceding the commencement of our era, or 1500 years earlier.

Before the discovery of the astronomical sculptures in Egypt, an unfounded opinion that the twelve signs of the zodiac, which were supposed to have been invented in that country, represent, allegorically, the agricultural labours peculiar to each of the twelve months of the year, led M. Dupuis, in his treatise on the *Origine des cultes* [a], to enquire what position of the colures would produce a correspondence of the seasons with the zodiacal signs; and he finds that such correspondence would take place if the summer solstice were to pass through the eastern stars in the assemblage which forms the constellation Capricornus. This position of the colure is supposed by him to determine the time when the zodiac was first divided, which, according to the known movement of the solstitial points in longitude, would be about 15,000 years before Christ. But the belief of even the existence of man during the long interval between this period and that of the earliest records, requiring too great a measure of credulity, the author of the hypothesis changed, as it is said, his idea and supposed the proper name of each sign to have been given, not from the character of the constellation occupied by the sun in any particular month, but from that of the constellation diametrically opposite to this, and ascending above the horizon at the time of sun-setting. Thus when the sun has

[a] Tom. III.

passed through Aries; at the time of his setting, the constellation Libra will be seen rising and, therefore, the latter denomination may have indicated the equality in the lengths of the days and nights at the commencement of the spring quarter, a circumstance to which Aries has no reference: this supposition, sufficiently reasonable in itself, receives additional strength from the practice which has been found to prevail among the Hindus and Chinese, of denominating the divisions of their zodiacs in a similar manner, and, if admitted, it would thence follow that, since the summer solstice must have coincided with the eastern stars of Cancer, the origin of the Egyptian zodiac might be fixed at about the year 2000 before the Christian era. Such is the position of the colure in the circular planisphere at Denderah, and the colure of the zodiac at Dehr being supposed to pass through the western stars of Virgo, the epoch of this monument would be about 2000 years earlier

But M. Biot, in the work above quoted[a], having determined the position of the pole of the world, in the planisphere at Denderah, to correspond with its place in the heavens about the year 713 Before Christ, takes this for the period to which the view of the celestial sphere represented in that monument belongs; then, by an ingenious argument founded on the positions of the longitudinal axes of the three temples with respect to the meridian, he accounts for the difference in the situations of the leading signs in all the zodiacs, and arrives at the conclusion that these monuments have nearly the same antiquity. He observes that, in the circular planisphere, the meridian line, which deviates from the longitudinal axis of the temple about 17 degrees eastward of north and passes through Cancer and Capricornus, divides the zodiacal signs in such a manner that the commencement of Leo is on the southern or upper side of the meridian with respect to the horizon; the western signs appear to be descending towards the northern or inferior side, and the other six signs to be ascending; and this is the order in which the signs are placed in the portico of the same temple, where the eastern signs proceed towards the naos as if to enter the temple,

[a] Page 126

and the others have their heads turned in the contrary direction as if they were quitting it.

But if, in the planisphere at Denderah, a line drawn through the centre of the circular zodiac and the lotus stem in which Sirius is placed be turned in the direction of the longitudinal axis of the temple at Dehr, which deviates from the meridian 71 degrees eastward of north, then a meridian line, drawn through the centre of the zodiac, will divide the signs so that Virgo appears to be culminating, or on the southern side of the meridian; the western, or descending signs, begin with this and end with Aquarius; and the ascending signs begin with Pisces and end with Leo; which is precisely the arrangement of the constellations in the portico of the temple at Dehr. Lastly, if the lotus stem in the circular planisphere be turned in the direction of the temple at Esneh, which deviates from the meridian 47 degrees eastward of north, the middle of Leo will be on the southern side of the meridian, so that half of this constellation will appear to be descending and the other half, to be ascending, agreeably to the disposition of the figures in the rectangular zodiac of the temple at Esneh.

As it is scarcely probable that these coincidences are accidental we may, perhaps, be allowed to consider them as arguments in favour of the hypothesis proposed by Biot, and to conclude that the intention of the artists who executed the different zodiacs was to exhibit a representation of the heavens about that hour at which Sirius arrived, by the diurnal motion, in a vertical plane passing through each temple. But though the epoch of all the monuments be thus referred to about the year 700 Before Christ, there are proofs that the temples themselves are of much more recent date. M. Champollion the Younger has recognized, in the contour of the circular zodiac at Denderah, the characters which express the word Autocrat; M. Letronne, also, and M. Gau have discovered, in the porticos of the same temple, and of one of those at Esneh, inscriptions showing that the former was built in the time of Tiberius, and the latter, during the reigns of the Antonines. Architects have, besides, observed that the temple at Denderah is built upon the foundation of one

still more ancient; and the advocates for the great antiquity of the sculptures are under the necessity of assuming that these scientific decorations have been copied from others of a like kind, which may be supposed to have existed on the original edifices.

M. Fourrier, in his *Description de l'Egypte*, supposes that the figures of lions, which so often occur among the hieroglyphics and statues about the temples of that country, were intended to commemorate the presence of the sun in the constellation Leo on the day of the summer-solstice; and, imagining that as early as 2500 years Before Christ the sun, on that day of the year, had left Leo to enter into Cancer, he infers that those temples, mentioning particularly that of Isis at Philæ (the approach to which is ornamented with rows of lions) must have been built previously to that time; but as the supposition is gratuitous, and we have seen that the sun was in Leo at the heliacal rising of Sirius in Egypt during all the time the empire existed, the inference drawn by M. Fourrier falls to the ground, and the correspondence of the emblems with the phenomena holds good for a period much later than 2500 years before the commencement of our era.

A taste for astronomical ornaments must have anciently existed in Persia and India, to the latter of which countries it was probably brought at some period when the religion and learning of Egypt were extensively diffused among the nations of the East. A marble monument, supposed to be a Chaldean zodiac, having on one of its faces a solar orb with a large serpent, which may be conceived to be that of Ophiuchus, besides several other figures appearing to represent constellations, has been dug out of the ruins of a palace on the banks of the Tigris near Bagdad [a]. And in the Philosophical Transactions for 1772 is inserted a letter from Mr. Call to Dr. Maskelyne containing the description of a zodiac which the writer had seen in a temple near Cape Comorin. It is stated to consist of twelve constellations, disposed on the four sides of a square, in the centre of which is the figure of a man having his hands joined as in prayer. The constellations resemble those which we have re-

[a] Maurice, Appendix to the Ruins of Babylon.

ceived from the Greeks except that Gemini are expressed by one figure, which is that of a man having a buckler on each arm, and that Capricorn is represented by a ram and a fish, which it may be observed, and the circumstance may be considered as an argument in favour of the antiquity of the monument, were probably the original figures by whose union that of the Greek constellation was formed. The near resemblance of the Egyptian or Greek zodiacs to that of the ancient Hindus and, consequently, the fact of an ancient communication between these people on the subject of astronomy is further proved from the MS. of Aben Ezra, in which, according to Scaliger, in his notes upon Manilius, there is a description of a Hindu zodiac resembling that seen by the English traveller just mentioned, but wanting the sign Scorpio, and having a fisherman in the place of Aquarius

Sculptured zodiacs, by Greek or Roman artists appear, also, to have been executed during the existence of the Western Empire, probably in imitation of some of those in Egypt. The most interesting of these is that discovered by Messrs. Dawkins and Wood on the ceiling of the temple of the Sun which was built at Palmyra in the age of Antoninus Pius or of Diocletian. In this monument the twelve signs are disposed in the circumference of a circle, but they appear to be moving in a direction contrary to that of the constellations in the heavens, as if a mere taste for variety in ornament, rather than any scientific principle, had been consulted in the execution. In the *Mémoires de l'Academie des Sciences* for 1708, there is a description of an ancient planisphere which, like the last, is evidently nothing more than a fanciful decoration; it was found among the ruins of Rome and represents the northern hemisphere, with Ursæ Major and Minor and the figure of a serpent in the centre; and having about it the signs of the zodiac three times repeated, in as many concentric circles.

The astronomy of the ancient Persians appears to have been a branch of that which, from the country of the Chaldeans, extended itself at some unknown but remote period to Egypt and Europe on the one side, and to India and China on the other; and the occasional notices concerning it, which occur in the

Zend-Avesta, may be offered as proofs of the opinion that the study of the heavens was of high antiquity in the territories situated immediately on the east of that which is, with much probability, considered as the birth-place of the science. This work is ascribed to a certain Zoroaster of whom no other particulars have reached us than that he was a great legislator and, perhaps, the sovereign of that part of Asia: the time of his existence, also, is as uncertain as that of the Egyptian Hermes; and, probably, the name of the former as well as of the latter has, at different times, been applied to different individuals, since by some he is made a contemporary of Belus, by others, of Darius Hystaspes.

In the Boundehesch, a work containing the cosmogony of the Parses and supposed to have been written by Zoroaster, it is said that Ormusd formed the light between the heavens and the earth: that he made the sun, moon, and stars, and divided the latter (probably those near the ecliptic) into twelve constellations. Each star in the zodiac is said to be seconded by 6,480,000 smaller stars, and all these are represented as soldiers ready to make war on the enemies (of Nature). Ormusd, it is added, has also placed, in the four quarters of heaven, four sentinels to watch over the stars, of these Taschter guards the east, Satevis, the west; Venana, the south, and Haftorang, the north, there is said to be, also, a great star, Meschgâh, in the midst of heaven for the purpose of giving further protection to the south when the enemy comes in great numbers [a]. Now it is impossible to form an opinion what can be meant by this enemy so mysteriously announced, but the above designation of the stars seems to correspond with "*The Host of Heaven*" which is used in the Scriptures, and with "*the attendants, or guards of the Supreme Deity*," which is the denomination applied by the Egyptians to some of the constellations and planets; and it has been attempted by modern astronomers to prove that four of the principal fixed stars were really situated in, or near, the four cardinal points of the horizon about the year 2200 B.C. which is the period usually assigned to the first Chaldean observations Delambre remarks that the longitude

[a] Zend-Avesta par M. Anquetil, Tom. II. Boundehesch.

of Aldebaran, at that epoch, was 11° 20′, and its latitude, 5° 30′ south; and as Antares differs from Aldebaran, in longitude, by six signs and has 4° 30′ south latitude, it follows that these stars were, then, very nearly in the points of the vernal and autumnal equinoxes; consequently one of them would be seen to rise near the east about the time that the other was setting a little to the north of the west. Now, it has been alleged that Tachter signifies the genius presiding over rain, and we know that the heliacal rising of Aldebaran was considered by the ancients as an indication of approaching storms; hence it is, with some propriety, inferred that this star and Antares were two of those alluded to in the Persian story The other two stars are less certain; Delambre supposes they might be Fomalhaut and Regulus, which were then, nearly, in the plane of the solstitial colure, and the former would be visible in the south at an altitude of about 12 degrees above the horizon at Babylon, while Antares and Aldebaran were, respectively, rising and setting: but Regulus must have been 34 degrees below the northern point of the horizon; consequently invisible at the same hour, in that latitude. If, therefore, it was meant that the four stars were at once seen in the situations above mentioned, we must look for some other star having the same longitude as Regulus, but having at least 34 degrees of north latitude; the star γ in Ursa Major is so situated and it is possible that this might be the star in question. M. Bailly [a] observes that the notion of four stars guarding the heavens seems to have extended to China, for, in the history of the astronomy of the Celestial Empire, it is said that there are four spirits which preside over the four seasons, meaning probably the four quadrants of the zodiac; and it is likely enough that this kind of observation would be made by any people among whom astronomy was in its infancy.

If we are to admit that the particular dispositions of the temples at Denderah and Esneh in Egypt were really given by design, we shall hardly be able to avoid concurring with Dr. Stukely in that part of his hypothesis concerning the Druidical monuments at Stonehenge and Abury in Wiltshire, which re-

[a] Astronom. Ancienne Eclaircsis. liv. IX. sec. 10.

lates to the direction of their longitudinal axes. The former of these is well known to consist of a great number of prismatic stones placed on end in the peripheries of four ellipses whose major and minor axes are, respectively, in the same right lines; the interior ellipse enclosing an area or cella: the entrance is supposed to have been at one extremity of the major axis and opposite to it, within the area, is a stone which seems to have been used as an altar. The Doctor's opinion is that the founders of the monument intended to dispose that axis in a direction tending from the south-west to the north-east, and to place the entrance opposite to the latter point of the horizon in order that it might receive the first rays of the rising sun on the day of the summer-solstice, it being, he observes, the custom of the ancients to celebrate their great festivals at that season[a]. The principal part of the work at Abury consists of one great range of stones, enclosing a circular area, within which are two double circular ranges, respectively concentric with each other but neither of them having its centre coincident with that of the former and containing circle: a line joining the centres of the two double circles is, also, supposed by Dr. Stukely to have been intended to coincide with that joining the north-east and south-west points of the horizon; but he observes that, in the temple at Stonehenge, the major axis deviates six or seven degrees southward from the north-east point and, in that at Abury, the line of the centre lies about ten degrees northward from the same point Now these different deviations, which may easily be conceived to be accidental, or to depend upon the situations of the points in which the sun first became visible, on the day of the solstice, above an horizon broken by the irregularities of the ground, are by Dr. Stukely supposed to have resulted from the employment of a mariner's compass to determine the directions of the axes of the temples; the needle being subject to a variation which is different in different ages, and the priests of the country being supposed to have considered, erroneously, that it coincided in direction with the true meridian of the place. We conceive it unnecessary to offer any argument to disprove the opinion that these monuments were *oriented* by means of a

[a] Stonehenge Restored.

compass, it being highly improbable that such an instrument would be used for that purpose, when the heavens present so many phenomena by which the end might be gained with much more ease and accuracy.

The opinion advanced by Dr. Stukely, that the Druidical monuments of this country were erected by the priests who were driven from Egypt by Cambyses, though not impossible, is wholly unsupported by evidence; they are, however, of great antiquity, and works of a similar kind appear to be frequently met with in the East, as we learn from Giovanni Finati, in the second volume of his life [a], where it is stated that at Djerash, the ancient Gerasa, and at Mayn, near the Dead Sea, the supposed Baal-Meon of the Scriptures, a number of great slabs of stone have been set together like boxes, four standing edgewise for the sides and one laid flat on the top, without any sign of art about them except their position. There is no appearance that these works have any relation to astronomy, but their resemblance to the Cromlechs of the north reveals an accordance of ideas, and affords ground to suspect that, in remote periods, there may have been an intercommunication between the people of the widely separated regions of Syria and Britain. That the monuments at Stonehenge and Abury were not unknown to the orientals is rendered probable from a passage in the second book of Diodorus Siculus where the writer, citing Hecateus, states that there is an island in the north, beyond the Celtæ, where is a sacred grove with a circular temple to which the priests resorted with their harps, to chant the praises of Apollo who, every nineteenth year, used to descend and converse with them. It is difficult to refuse our assent to the opinion, expressed by Maurice, in his *Indian Antiquities* [b], that the statement refers to such works as those above mentioned, and the periodical visit of Apollo seems to imply that the Druids were acquainted with the lunar cycle; but it will not be necessary to follow the author of the work last quoted in his supposition that the elliptical temples of the Druids were designed in imitation of the forms of the planetary orbits, or that the crescent temples in Anglesea

[a] Life of Finati, by Banks.

[b] Vol. VI.

and Orkney were dedicated to the Moon. We may observe here that the astronomy of the Greeks and Orientals seems, about the commencement of the Christian era, to have reached the north of Europe; for Cæsar, describing the manners of the Gauls, says [a] "the Druids teach many things relating to the stars and their motions, the magnitude of the earth and the universe, the nature of things and the powers and prerogatives of the immortal gods": and it is probable that what was taught by that order of men in Gaul was taught also in Britain, which seems to have been the chief seat of the hierarchy.

The use of the solar year, at an early age, is ascribed by Bailly [b] to the Scandinavians on the ground that in the time of Olaus Magnus, about the year 1000 of our era, they were accustomed to celebrate on the forty-fifth day after the winter solstice a certain festival which, as Rudbeck asserts, in his treatise *de Atlantica*, was originally intended to take place at the first appearance of the sun after being forty days invisible; that is on the twentieth day after the said solstice; and the conclusion of Bailly is that, between the first institution of the festival and the time of Olaus Magnus, the period was retarded, with respect to the solstice, by twenty-five days in consequence, he supposes, of the length of the year being assumed at 365¼ days; this retardation corresponds to an interval of 3300 years and, therefore, he considers that the origin of the festival and the introduction of the solar year in that part of the world took place about the year 2300 Before Christ. But M. Bailly should have remarked that by using a year of 365 days the celebration of the festival would anticipate the season by about a quarter of a day yearly, and this, at the end of about 1430 years, would bring it to the forty-fifth day after the solstice; consequently its first institution might be dated from about the year 400 Before Christ. And, if we consider that the climate in which the sun remains below the horizon during forty days passes through the middle of Lapland, it will not appear probable that the festival in question should have any pretensions to a higher antiquity.

[a] De Bello Gallico, Lib. VI. sect. 13.

[b] Bailly, Astr. Anc. Eclairciss. liv. III. sect. 2.

CHAPTER VIII.

ORIGIN OF ASTRONOMY AMONG THE GREEKS.

A theory of the celestial movements developed in the Greek astronomy.—The Greek astronomy probably derived from the Egyptian.—Thales established the first school of Greek philosophy.—Works ascribed to him.—He predicts an eclipse of the sun.—Tenets of Anaximander.—Removal of the school of Thales to Athens—Theory of the universe ascribed to Anaxagoras.—Opinions of this philosopher concerning the stability of the heavenly bodies.—Sentiments of the Greek astronomers concerning the sun and moon.—A supposed change in the position of the earth's axis.—An opinion concerning meteoric stones.—Doctrines of Anaximenes.—The school of Pythagoras in Italy.—Opinion of the mobility of the earth.—Of an antochthone and invisible planets.—Harmony of the celestial spheres—Hypothesis of vortices proposed by Democritus.—The lunar cycle of Philolaus.—The cycles of Meton and Calippus.

In attempting an account of the ancient astronomy of the East we have been compelled, from the paucity of documents, to describe the probable rather than the real march of discovery, and to reason from conjectures rather than from facts: we now proceed to consider the astronomy of the Greeks and later Egyptians whose yet existing works exhibit the progress of the human mind in investigating the laws of the celestial movements, and in inventing a mechanism which may represent them. We must not, indeed, expect to find a complete development of that principle by which, in the age immediately preceding our own, the true cause of those movements has been explained and the constitution of the universe made evident; yet we shall perceive so many hints, obscurely indeed announced, but indicating a conception of the hypotheses now generally admitted, and of the facts which recent observations have confirmed, as almost to justify the opinion entertained by a late French author that the most important discoveries ascribed to the moderns originated, or were recognized, in the schools of Greece. But though it is certain that such an opinion is not supported by a reasonable interpretation of the expressions used by the ancient philoso-

phers, yet we shall find sufficient cause to admire the sagacity which, with observations of so rude a nature as those they had it in their power to make, and with a calculus so far inferior to that which we now possess, enabled them to account for so many of the phenomena of the heavens, and to offer so feasible a solution of the great problem of the celestial motions. It must also be observed that the system of the universe invented in those schools maintained its ground during more than two thousand years, and only yielded to the improvements made in the instruments of observation since the revival of learning in Europe. These improvements, joined to the happy adoption of a principle either unknown or but little regarded before his time, permitted Newton to unfold a theory which is not likely to be shaken during the continuance of that order of things which it has so satisfactorily explained.

All the more ancient hypotheses may be said to have had their use in connecting together the results of individual observations; and thus, have contributed, in some measure, to the progress of science; but it was impossible that they should stand when, by multiplied observations, the minute irregularities in every part of the orbit of the Moon, or of each planet, were discovered. The first two principles, the circular and uniform motions of celestial bodies, were arbitrary assumptions, and the original system formed upon them was insufficient to account for any but the most obvious phenomena, and, instead of being able to deduce from it the explanation of any newly observed inequality of motion, astronomers were obliged, for this purpose, to make additions, in the nature of excrescences, to the machinery before imagined. These additions, however, did not, as may be supposed, combine with each other and with the original hypothesis so as to satisfy the different phenomena, and, in fact, it happened that while one inequality of motion was explained by them another was contradicted; they, moreover, at length rendered the machinery of the heavens unmanageably complex, and, therefore, nearly useless for the purpose of facilitating astronomical computations, long before it was superseded by the modern theory of gravitation.

The writings of Homer and Hesiod contain all that is known

of the first state of astronomy in Greece: and this amounts, as we have said, to little more than the names of a few constellations, the principal of which Homer has introduced in the fifth book of the Odyssey, where Ulysses, in his bark, on leaving Calypso, is made to observe, "the *Pleiades* and *Bootes*, the *Hyades* and Bold *Orion*; the *Bear* which is called the Wain; the unwearied sun, and the full moon, and all the stars by which, like a crown, the heavens are surrounded." We may, therefore, conclude that, in the age of those poets, the science was at its birth in that country; or that the Greeks had just then received its elements from some other people.

Little doubt can be entertained that the Greeks derived their first notions of the sciences, particularly of astronomy, from Egypt or Syria, either by means of intelligent men of their nation who travelled into those countries to seek for information, or by means of the chiefs who, for the purpose of conquest or colonization, conducted their warlike bands from thence towards the west. We are aware that the expeditions, and even the existence of such men as Uranus and Atlas as well as the exploits of Sesostris, have been called in question, but surely without sufficient reason, since, during the many ages in which the profession of arms enjoyed the highest consideration, and when the rapid increase of the human race rendered emigrations absolutely necessary, it is impossible that multitudes should not have abandoned their native soil, though no account of their movements has been preserved; on the contrary, it is in the highest degree probable, not only that the tide of conquest should have flowed into the remotest accessible regions, but that the arts and sciences of the more enlightened people should, by such means, have been communicated to those who were less so: on this account we cannot hesitate to admit that what is related by Diodorus Siculus concerning those personages may have some foundation in truth. In his third book he informs us that Uranus, who held in subjection a great portion of the earth, towards the west and north, applied himself to the observation of the risings and settings of stars, that, from the movements of the sun and moon, he taught the length of the year and its division into months; and that, in consequence of the admira-

tion excited by his knowledge of celestial things, divine honours were paid to him and the universe was called by his name. In the same book it is related that Atlas extended his conquests to the regions in Africa bounding the Western Ocean, and gave his name to a mountain in that part of the world. It is added, as a report however, that he had an exact knowledge of astronomy and that, because he had executed an artificial sphere representing the heavens, he was supposed, and the opinion is alluded to by Æschylus, to have carried the universe on his shoulders. In the fourth book it is stated that Hercules introduced the knowledge of the celestial sphere to the people of Greece, and that he was said to have received the burthen of the universe from Atlas, which seems to imply that one of the labours of the hero consisted in communicating to the Greeks a knowledge of the sciences which he had acquired in some expedition towards the west.

It is evident, however, that astronomy could not have been in a state of maturity in the East at the time the Greeks received it from such of their countrymen as had studied among the Egyptians or Asiatics; since, if it were so, those persons would have imparted it in a more advanced condition than, by the accounts which have been transmitted to us, we find it to have been; for what they taught on their return appears to have consisted only of a few simple and elementary circumstances, and there is no hint given that they had acquired the knowledge of any thing more profound.

The first intimation we have of any Greek professing the science of astronomy is contained in the works of Herodotus, and consists in the mention of an eclipse of the sun which had been predicted by Thales, a native of Miletus in Asia. A short account of the life of this philosopher is given by Diogenes Laertius, who relates of him[a] that, when a youth, he was one day led out of the house for the purpose of contemplating the stars and, falling into a ditch, his conductress exclaimed, "*why, O Thales, do you seek to comprehend the things which are in the heavens when you are not able to see those before your eyes?*" The story, which is alluded to by Socrates in Plato's dialogue

[a] In vita Thaletis.

Theætetus, has the air of an invention, but something remarkable is generally related concerning the early life of persons who have distinguished themselves by superiority of talent, and there is nothing to prevent our giving as much credit to this as to many others of a similar nature: if true, the exclamation may indicate either a sarcastic, or a moralizing spirit in Thressa, the attendant, and it affords, at the same time, a proof of the inclination of her young charge to philosophical pursuits.

After performing the duties of a citizen Thales employed himself in the study of the system of nature, but Diogenes observes that he left behind him no monument of his discoveries, and that whatever is known concerning him is drawn from the works of Phocas the Samian. He is said, for the purpose of acquiring information in philosophy, to have made a voyage to Egypt; yet, by a strange inconsistency, it is asserted that he taught those who were his masters in the sciences how to measure the height of the Pyramids by the length of the shadows they cast, which is one of the most simple examples of practical geometry. the truth probably is that, in Egypt, Thales learned this, among other subjects connected with the elements of astronomy. On his return to his native country he made a profession, after the manner of learned men in those times, of giving public instructions to such as chose to become his disciples, on which account he is spoken of as the founder of the Ionian school and the father of the Greek philosophy.

If we may depend upon the obscure hints contained in the works of those authors who have incidentally made mention of this philosopher, it would appear that, in his time, the form of the earth was recognized, for he is said to have asserted that it was globular and that it was situated in the centre of the universe. It is added that he supposed the fixed stars to be attached to the surface of a sphere, and, according to Plutarch[a], he divided the earth into five zones and described the situations of the Equator, the Tropics, the Arctic and Antarctic circles: if these circumstances be true they prove that this manner of dividing the visible heavens, for the purpose of distinguishing the relative positions of the stars, had then been adopted; the last two

[a] De Placitis Philosophorum, Lib. II. cap. 12.

circles, however, in the time of Thales and long subsequently, had not the same signification as at present, since they were applied to those parallels of declination beyond which, in the northern and southern hemispheres respectively, were situated those stars called circumpolar; that is, which towards the north, in any given latitude, never set, and towards the south, never rise.

Diogenes Laertius relates that there were ascribed to Thales two works concerning the equinoxes and solstices; and it is inferred that he had made observations to determine the days of their occurrence in order to ascertain the length of the year: this is by no means unlikely, but the result of his enquiries is entirely unknown. He is, also, said to have attempted to give an account of the physical constitution of the universe; and by Cicero[a], who designates him the first (Greek) enquirer concerning these things, he is made to assert that water was the primitive element, of which the Deity made all things in nature: from this hypothesis, but in a much earlier age, is said to have originated the fancy that the earth rested on the ocean like a boat.

But what most particularly distinguished Thales is the above-mentioned prediction of an eclipse which, as the phenomenon occurred at a critical moment, naturally excited considerable attention, and must have added greatly to the reputation of the philosopher. Herodotus, who relates all that is known of the circumstances, observes that in the midst of an action which took place in the sixth year of the war (between the Medes and Lydians) the day was suddenly changed into night:—Τῷ ἕκτῳ ἔτει συμβολῆς γενομένης, συνήνεικε ὥς τε τῆς μάχης συνεστεώσης, τὴν ἡμέρην ἐξαπίνης νύκτα γένεσθαι.[b] He adds that Thales the Milesian had predicted the year in which the eclipse would take place and that the hostile armies, when they saw the darkness, desisted from the battle. This eclipse has been the subject of much discussion. The father of history neither mentions the particular year nor month when it occurred; but, as it was probably total, or nearly so, this circumstance has afforded some clue to guide modern astronomers in the research;

[a] De Nat. Deorum, Lib. I. cap. 10.

[b] Clio, sect. 74.

and, calculating by the tables at present in use, they have arrived at the conclusion that the eclipse might have happened in the year 585, 603 or 621 Before Christ. Cicero[a] and Pliny[b] say that it took place during the reign of Astyages. It is probable enough that Thales announced the time at which the phenomenon would occur within a month: for, as is observed by Delambre, this was in his power, with the aid of the cycle of 18 years, a knowledge of which he might have obtained in Egypt; and the silence of Herodotus respecting the time may be accounted for by supposing that it did not enter into the plan of his work to record the particulars minutely. Two other eclipses are said to have been predicted by the ancient Greek astronomers; one by Eudemus, the author of a history of the science, which is lost, and the other by Helicon of Cyzicene who, according to Aristotle[c], announced to King Dionysius the time of its occurrence, which is said to have happened conformably to the prediction.

The Ionian school which had been founded by Thales seems to have produced several celebrated men, among whom Anaximander, Anaxagoras and Anaximenes are particularly mentioned as persons who cultivated and taught the science of the stars: no record, however, remains, of any celestial observation made by these philosophers, and the accounts we have of their works only shew that, from such data as then existed, they reasoned profoundly on the constitution of the universe.

Anaximander was born about 600 years before Christ and, therefore, probably, he was the disciple and immediate successor of Thales: like his distinguished master he considered the earth as isolated in space, and according to Diogenes Laertius[d], both of these philosophers maintained that it was of a globular figure. These are the first occasions on which we find the spherical form of the earth distinctly asserted and, perhaps, the opinion has no better foundation than a fortunate conjecture; for though the curvature in every direction, from the place of a spectator, might easily be inferred from the appearances presented by a lofty object, as the mast of a ship, when approaching to, or receding from him; and the curvature in the direction of the

[a] De Divinatione, Lib. I. [b] Nat. Hist. Lib. I. cap. 12.
[c] De Cœlo, Lib. II. cap. 6 [d] In loc. cit.

meridian is evident from the fact that the same stars, when in that plane, change their apparent altitudes with a change in the place of the observer; yet, as the part of the earth's surface then known bears but a small proportion to the whole, the generality of the inference must have admitted of doubt; and we find that the reason alleged for the sphericity of the earth must have been far from carrying conviction to every mind, since Leucippus and others entertained the opinion that it was cylindrical, or had the form of a column. But the tenet which, really, does honour to the judgment of Anaximander is that of the earth's movement about its axis; an hypothesis which he is said to have maintained, though his arguments in support of it have not been preserved. Anaximander must, consequently, have succeeded in the difficult task of overcoming the prejudices of his senses; he must have elevated his mind to the conception that the diurnal motion of the celestial sphere is only apparent, and that the appearance is caused by that of the earth in a contrary direction: a bold step in that age when a number of facts by which the truth of the hypothesis might have been established were entirely unknown.

The same philosopher held a sound opinion relative to the moon for, according to Diogenes Laertius, he taught that she shines by a light reflected from the sun: if, however, he could raise himself to this idea, it seems that he failed in persuading his contemporaries of its justness, since we find that, about the same time, very absurd notions were entertained concerning the phases or appearances of that luminary. He failed also, as might be expected, in his determinations of the magnitudes of the celestial bodies; for we learn from Diogenes Laertius and Plutarch that he supposed the sun to be equal in bulk to the earth, and to be constituted of fire, or rather, within its mass, to contain a fire which radiates in every direction from apertures in its surface. He asserted, also, that the circle of the sun, meaning, as Casaubon supposes, its apparent yearly orbit, was twenty-eight times as great as the earth, a remarkable instance of the very inaccurate notions then entertained of the universe.

Anaximander also appears to us in the character of a practical astronomer and geographer. Diogenes Laertius relates that he

set up a gnomon at Lacedæmon, and observed the times of the equinoxes and solstices, but, probably, this was not the first instrument of the kind in Greece, since the same writer affirms that Pherecydes, who was contemporary with Thales, had constructed, in the island of Scyrus, a machine, which could have been no other than a gnomon, for showing the conversions of the sun, that is, the days of the solstices It is added that Anaximander described the boundaries of the land and seas, and executed a horoscope or planisphere and an artificial globe: the former, probably, was of the same nature as the sculptured zodiacs in the Egyptian temples, and the other may have been intended to represent the surface of the earth or heavens These mimic worlds have, ever since, been of general use and may, certainly, be reckoned among the most pleasing works of art, by enabling the student to contemplate the phenomena of the celestial bodies in the closet, or the forms and situations of remote regions of the earth without removing from the place he inhabits.

Soon after the time of Thales it is probable that the philosophers professing the doctrines of his school found, among the people of Athens, who then, under the government of Pericles, began to rank high in political power, in sciences and arts, and in refinement of manners, a more ample field for the display of their talents than that afforded by an Asiatic town; for it appears that, during the reign of this magistrate, Anaxagoras transferred the Ionian school from Miletus to that city, where he, unfortunately, though professing, as Jamblichus relates[a], to desire life only that he might contemplate the heavens, suffered persecution for his philosophical opinions on the ground that they were inimical to the religion of the state: he was sentenced by the Athenians to die, but the punishment of death was, through the interest of Pericles, commuted for perpetual banishment. The fate of the Greek philosopher resembles that of Galileo who, in a later and more enlightened age, and when men were under the influence of a religion which consists rather in purity of heart than in the belief of any particular dogmas was,

[a] De vita Pythag. Lib. II. Cap. 8.

also, the victim of spiritual tyranny. It is probable, however, that the troubles in which the ancient, as well as the modern sufferer were involved, are to be ascribed to some indiscretions, by which they had rendered themselves personally obnoxious to the ministers of religion, rather than to any impiety with which their philosophical speculations could be charged.

In his writings concerning the constitution of the universe, Anaxagoras seems to have set out by assuming that nature always acts in the most perfect manner, a principle to which the Greek philosophers, at all times, adhered; he from thence concludes that the actual phenomena can be no other than they are; and he does not attempt, or, probably, he thought it impossible, to give any other reason for their existence: this defect, however, was felt by the wisest men of that and the following age, who expressed an ardent desire to know something of the second causes which are operative in the works of nature. In Plato's dialogue entitled Phædo, Socrates is made to tell Cebes that he had perused the works of Anaxagoras in expectation of finding whether the earth was broad or round, probably meaning whether it was of a plane or globular form, and whether it was in the centre of the universe or not: he adds that he was extremely desirous of knowing the cause of the existence of all beings, but he owns that he was disappointed; for, says he, Anaxagoras only ascribes them to the power of the Supreme Intellect, which has arranged them in their proper ranks and classes, and disposed them in the best possible manner. This kind of explanation seems to have prevailed among the learned almost to our own times, and abounds in the writings of Aristotle who, however, seems to have merely adopted a principle which long before had been assumed.

We perceive, from what Socrates has said, that Anaxagoras could not have been condemned under pretence of Atheism, since he admits the existence of a Supreme Intellect, though he might have denied the divinity of the beings which were the objects of worship in the heathen world. We learn, also, that the Greeks, about this time, were familiar with the notion that the earth is not coincident with the centre of the universe though, further on, Socrates considers the opinion that it is so as one which was very gene-

rally admitted among philosophers, and he endeavours to give Simmias a reason why the earth should remain unsupported in space: his argument is that the earth requires no air to prevent its falling since it is, as it were, wrapped about and pressed equally in every direction by the universe. It appears from this expression that Socrates thought the earth was held *in equilibrio* by equal and opposite forces acting upon it from all the celestial bodies; a notion which seems to coincide with that ascribed by Plutarch [a], to Parmenides, who, in explaining the cause of the earth's stability, is made to say that no reason can be given why it should fall to one side rather than to another; and therefore, it rests. An allusion to the support of the earth by the air is found also in the *Clouds* of Aristophanes, where the chorus is made to address that element as a "great king who holds the earth suspended"; and it would seem that there were, then, many persons who thought the earth was kept in its position by winds tending towards it from every part of the surrounding space; a fancy which Achilles Tatius [b] illustrates by observing that a grain of corn remains at rest in the middle of a bladder when, on blowing into the latter, the wind is reflected from its interior surface towards the centre. We may add, however, in this place, that Tatius, in explaining the cause why the universe remains at rest in infinite space, makes Chrysippus observe that it consists of four elements, earth, water, air, and fire, of which the two former, occupying the centre, are endowed with *gravity*, or have a tendency to descend, and the two latter, surrounding the others, are endowed with *levity*, or have a tendency to ascend: he then compares the universe, thus compounded, to a mass composed of two such bodies as lead and cork, of equal weights, bound together; and states that if this mass were thrown into the sea the lead would prevent it from rising to the surface and the cork would prevent it from sinking, whence, consequently, it would remain at rest at any depth; from which circumstance the quiescence of the universe is meant to be inferred. But the opinions of the Greeks were, at all times, far from being settled on the subject of the stability of the earth.

[a] De Placitis, Lib. III. Cap 15

[b] Isagoge, Cap. IV. in Petav. Uranolog

Plutarch[a] and Achilles Tatius[b] state that Xenophon and Xenophanes considered it to be infinitely deep in one direction; and, consequently, maintained that it could not fall, and Diogenes Laertius[c] ascribes to Thales the opinion that it was sustained by, and floated on, the waters. But the more general argument held out in support of the immobility of the earth was that, since heavy bodies tend towards its centre, that centre must be fixed in space; yet, according to Laertius[d], Democritus proposed the notion that the earth was continually falling: in fact every possible opinion appears, at one time or another, to have been held, in the ancient schools, respecting the place occupied by the earth among the bodies of the universe.

The opinions of men who are in nearly corresponding conditions with respect to civilization and arts or sciences are found to be nearly allied to each other, and we may, in what we have learned of the sentiments of the Hindus, trace many points of resemblance to the notions of the Greeks and Egyptians. Thus we find that the *Jainas*, an ancient people of India, had used in their writings expressions which led their commentators, in later times, to suppose they held an opinion that the earth performed a revolution in space: but Bhascara, one of those commentators, who lived in the twelfth century of our era, has endeavoured to shew that such expressions had no other meaning than that the earth, being heavy and without support, must continually descend; and that they had no relation to any movement of revolution. Bhascara himself, however, denies that the earth can be continually falling; and urges, as an argument against the opinion, that if so, an arrow shot vertically upward would not return when the projectile force was expended, since both earth and arrow would be descending: and, he observes, it cannot be replied "the earth moves slower and is overtaken by the arrow", for the heaviest bodies fall with the greatest velocity, and the earth is heavier than the arrow; therefore cannot be overtaken by it[e].

The enquiry into the cause of the circular motion of the

[a] De Placitis, Lib. III. Cap. 9.
[b] Isagoge, ubi suprà.
[c] In vita Thal.
[d] Lib. IX.
[e] Asiatic Researches, Vol. XII. On the notions of the Hindus.

heavens is now for the first time alluded to, and it is probable that, more anciently, it was thought a sufficient explanation of this kind of movement to say that it is peculiar to incorruptible bodies such as the stars, while motion in a rectilinear direction is peculiar to terrestrial substances. Theon, the commentator of Ptolemy, has expressed this opinion which, however, bears the mark of the older schools of Greece, and he has illustrated the latter part by the fact that, of the bodies near the surface of the earth, heavy ones tend in right lines from the circumference towards the centre and light ones in a contrary direction. But Anaxagoras, in reply to the question why the celestial bodies do not fall from their places towards the earth, asserts that their actual state is preserved by the rapidity of their movements; and, though we have no reason to think that this philosopher understood the laws of centripetal and centrifugal forces, yet his assertion indicates an idea that a revolving body might be held *in equilibrio* between such forces. That a body moving in the circumference of a circle endeavours to recede from the centre is a fact which could not escape the notice of the ancients, who were so familiar with the use of slings in discharging stones; and Plutarch actually makes Anaxagoras compare the motion of the moon round the earth to that of a stone in a sling, which, he observes, is subject to the action of two forces at once; meaning the retaining power of the cord and that by which, in consequence of the movement of the hand, the stone tends to escape in the direction of a tangent to the curve it describes. The idea that a revolving motion is produced by the actions of two forces in rectilinear directions must, therefore, have been entertained at this time, and we can readily admit that Anaxagoras drew from thence the opinion which has been ascribed to him concerning the stability of the universe. Aristotle [a] states that Empedocles and other philosophers held a similar notion, and he illustrates it by the well known fact, that water in an open vessel will there remain while the vessel revolves about a centre though, in some part of its revolution, it may become inverted.

Diogenes Laertius says [b] that Anaxagoras considered the sun

[a] De Cœlo, Lib. II.

[b] Lib. II.

to be a burning mass of iron larger than the Peloponnesus; an opinion which implies that the sun is at a distance from the earth only equal to about nine or ten diameters of the latter; but it is probable that such an expression was merely intended to convey, to the uninformed populace, a notion that the sun was of immense magnitude by comparing it with an extent of territory which in those days was, no doubt, familiarly spoken of as very considerable. Archelaus, who was of the Ionian school and contemporary with Anaxagoras, is said to have maintained the more reasonable opinion that the sun was of the same material as the fixed stars; but this was, perhaps, simply an inference from the general notion that all the heavenly bodies were of the nature of fire. According to the writer above-mentioned, Anaxagoras offered a conjecture that, like the earth, the moon had habitations, hills, and valleys; an opinion also expressed in some pretended Orphic verses preserved by Proclus.

> Μήσατο δ' ἄλλην γαῖαν ἀπείρατον, ἥντε σελήνην
> Ἀθάνατοι κλήζουσιν, ἐπιχθόνιοι δέ τε μήνην,
> Ἣ πολλ' οὔρε' ἔχει, πολλ' ἄστεα, πολλὰ μέλαθρα.[a]

"The Father made another earth called *Selene* by the immortals, but, by men, the moon, containing many mountains, cities and mansions." And it may readily be conceived that such notions would be formed at the first view of her disc; for the light and dark spaces which are so visible to the naked eye naturally suggest the notion of an elevation and depression of surface, and an easy analogy would lead to the supposition that this celestial body was inhabited, when the resemblance of her surface to that of the earth was perceived. It is well known that this supposition has continued to be popular even to our own days, though the constancy of her features and the absence of any collections of water, like the seas of the earth, the existence of which the most powerful telescopes have not been able to detect, nearly demonstrate that the contrary is the fact. Plutarch, who seems, in his work *De Facie quæ in orbe Lunæ apparet*, to have collected the opinions of most of the distin-

[a] Proclus in Timæum, Lib. III.

guished men among the ancients concerning the heavens, represents the spots which appear on the surface of the moon, and which, he observes, constitute figures resembling eyes and lips, as deep cavities, like the gulfs of the earth, which the light of the sun does not penetrate, he concludes that this celestial body may have water and air, and that it may produce and nourish animals endowed with respiration and heat.

Nearly the same ideas have been expressed by some of the astronomers of the present day, who observe that the mountainous scenery of the moon bears a strong resemblance to that of the Alpine regions of the earth, and they consider the cavities as the beds of seas which have once existed in that luminary. Mr. Schrœter, believing that he has discovered an atmosphere about the moon, and conceiving that she may enclose a liquid proper for the support of organized bodies, boldly asserts that this celestial body is the abode of living and intelligent beings, of whose existence he thinks he has discovered certain indications[a]. If this astronomer had lived in the days of Pythagoras or Plutarch he probably would have added, in the words of the latter, "*the intelligent beings who inhabit the moon are of slender forms and are capable of receiving support from any aliment whatever.*" But, however interesting may be the picture he has presented, of the supposed state of nature in the moon, it is too certain that his opinions on this subject are ill supported by observation, and we are rather disposed to consider our satellite as the mere nucleus of a world, a mass of naked rock destitute of any of the elements capable of supporting animal or vegetable life. We must not omit to observe that Empedocles[b] is said to have considered the moon as a fragment struck off from the sun; a notion since entertained by the celebrated Buffon concerning the earth, moon and all the planets. Vitruvius, in his treatise on Architecture, says that a certain Berosus, whom he describes as a lecturer on philosophy, in Asia, taught that the moon was a globe, half luminous and half of a blue colour; and that, when it approached the sun, being attracted by the force of his rays, it turned its bright side to that luminary and became invisible to

[a] Voiron, Hist. de l' Astronomie, Art. II.

[b] Achilles Tatius, Isagoge, Cap. XVI. In Petiav. Uranolog.

us, from the colour of the other part being confounded with that of the air. It is probable that Vitruvius borrowed this account from Cleomedes who, besides ascribing the notion to Berosus, makes the latter assert that the moon has several movements, and he particularizes the diurnal motion, the motion in longitude and latitude, and the rotation on her axis[a]: this expression, if understood in the sense assigned to it by modern astronomers, would seem to indicate that the ancients, from the fact that the moon presents to us always the same face, had arrived at the conclusion that she revolves on her axis in the same time that she makes one revolution about the earth. Cleomedes adds "it was well known to the ancient philosophers that the moon is enlightened by the sun", and he derives her name, Σελήνη, from Σέλας, because she is continually acquiring new phases by his light.

We may here remark that the Greeks, when their writings or discourses were not intended for the learned, seem, in speaking of the heavenly bodies, to have occasionally expressed themselves in terms adapted to the ideas of the vulgar; and it appears that some among them, erroneously taking such expressions in the literal sense, have seriously set themselves to refute the opinions they convey. Thus, the disciples of Epicurus are supposed to have asserted that the sun, moon and stars are no larger than they appear to be; and, though no one can believe that such a notion was really held by a person having any pretensions to the character of a philosopher, yet Cleomedes[b] gravely argues against it from the fact that, when the sun is rising behind a mountain, the edges of his disc are often, at the same time, visible on the opposite sides of the mountain; and the inference is that the sun, though, apparently, only about one foot in diameter, must be, in reality, larger than the mountain itself.

The returns of the sun at midwinter and midsummer from the tropics towards the equator, without any visible cause, appear to have excited some attention among the ancients in the infancy of the Greek astronomy: and we learn from Plutarch[c] that

[a] De Mundo, Lib. II. De Lunæ Propinquitate

[b] Ut supra. [c] De Placitis, Lib. II cap. 23.

Anaxagoras endeavoured to account for them by supposing the dense air of the polar regions to resist the passage of the sun northward or southward of those parallels of declination. In the life of this philosopher, by Diogenes Laertius, it is alleged that he supposed the stars were attached to the superficies of a dome which revolved, originally, about an axis perpendicular to the horizon, and that subsequently, the axis became inclined to that plane: this, which is quite inconsistent with the opinion that the earth is of a globular figure, may seem, however, at first sight, to imply a knowledge that the earth's axis was subject to a change of position; but it is very certain that there then existed no means of ascertaining this fact, and it is probable that, in the effort to exhibit a system of the universe possessing the utmost simplicity, the observed obliquity of the axis, alone, suggested the notion of its former perpendicularity. At a period long subsequent to the time of this philosopher, when the variation in the position of the earth's axis was discovered, it immediately occurred to astronomers that there might have been a time when the axis coincided with that of the ecliptic, and that there might come a time when it would be again in that situation. Impressed with this idea, men of lively imaginations found pleasure in contemplating a state of society on the earth when the temperature of the spring season should prevail during many ages; but an improved analysis has now dispelled the reverie, and shewn that such coincidence never did, nor can, take place.

From a meteoric stone which, according to Pliny, fell, in the days of Anaxagoras, near the river Egos in Thrace, this philosopher is said to have imagined that the stars were formed of material substances which exhale from the earth; probably meaning that the planets are of the same nature as the earth, and that detached portions of them are occasionally thrown upon it, opinions not very remote from those which are, even at present, entertained. For, setting aside the common notions that the meteoric stones are formed in our atmosphere, or projected from volcanoes in the moon, since the discovery of the four new planets between the orbits of Mars and Jupiter, which are thought to have been produced by the explosion of some great planet formerly existing in that region, philosophers have

been led by analogy to ascribe the descent of these stones to the same cause; a number of little fragments were detached, they suppose, along with the greater masses and, being thrown beyond the limits of the attractive powers existing in the larger fragments, they fall upon the surface of the earth when they happen to arrive within the sphere of its influence. The nature of the aeroliths affords some argument in favour of this hypothesis, for they consist of sulphur and ferruginous matter and possess the magnetic virtue; qualities which are believed to characterize the substance constituting the internal part of the earth and, probably, of every planet.

Anaximenes, the last astronomer who was considered as a disciple of Thales, was born about 530 years before Christ. His sentiments concerning the constitution of the universe appear to have been nearly the same as those held by Anaxagoras, for what is said of one is, also, asserted of the other, and, indeed, it must not be supposed that every opinion ascribed to either of the Greek philosophers by name was actually maintained by him exclusively; the ancient writers often attributing to an individual the doctrines which were common to many persons of the same school. Plutarch[a] states that Anaximenes first taught the materiality of the heavens; and, according to Diogenes Laertius, he asserted that the stars moved not above but about the earth; an expression which seems to indicate that he was opposing a vulgar notion concerning the revolution of the celestial bodies within a vault resting on the earth as a basis. But Pliny relates of Anaximenes a circumstance of more importance than his speculations upon the nature of the universe, which is that he set up, at Sparta, an instrument to serve as a sun-dial; of what kind it may have been we are entirely unacquainted and, possibly, it was that which Diogenes Laertius ascribes to Anaximander; but, if it was used for the division of days into portions, it would follow that the Greeks must, then, have acquired some knowledge of the regularity of the solar movements and of their application to the measurement of time. A simple gnomon casting its shadow upon a horizontal plane might be that which is meant, and the hour lines may have been traced

[a] De Placitis, Lib. III. cap 10.

mechanically, without the aid of any rules derived from theory: but it is conceivable that the dial might have been of the kind now called equatorial, that is, it might consist of a circle whose plane was parallel to that of the equator: on such a plane the hour lines make equal angles with each other and, therefore, could be easily traced; and the style, by whose shadow the hours are indicated, is perpendicular to the plane of the circle.

Pythagoras is the next distinguished philosopher of whom any account remains, and he is as much celebrated for his discoveries in pure geometry as for his astronomical notions. It is unfortunate that we have none of the works which he must have composed, consequently we are uncertain what is due to himself and what belongs to those persons who adopted and developed his tenets; and who, to gain authority for their opinions, ascribed them to their master. Like most of the learned men among the Greeks he travelled into the East; and we learn from Jamblichus[a] that he passed twenty-two years among the priests of Egypt, applying himself to the study of geometry and astronomy, and causing himself to be initiated in all the sacred mysteries. From that country he was carried by the soldiers of Cambyses to Babylon, where he conversed with the Magi and, during the twelve years that he remained there, learned many things relating to numbers and music. If we may believe Porphyry, his desire to obtain information carried him as far as India; where, if it be a well founded notion that philosophy had, in those early times, made greater progress than in Europe, it is possible that he might have learned some of those doctrines which he is supposed to have, afterwards, promulgated. Pythagoras established himself at Crotona in Italy and thus, perhaps, contributed to the dissemination of the Greek philosophy in the west, by the instructions which he, or his immediate disciples, communicated to the people of Magna Græcia; from whom the Etrurians may have caught that portion of science by which they were distinguished above the other Italians.

According to Aristotle, in his second book of the Heavens, the Pythagoreans imagined the universe to be divided into spherical regions which were occupied by bodies or elements of different

[a] De vita Pythag. Lib. I. cap 4.

degrees of excellence; they considered that the centre, which is the place of honour, was assigned to fire, the most noble of the elements, and about this they supposed the stars, of which the earth was esteemed as one, to revolve. Plutarch, in his life of Numa, states that this prince had built, as a representation of the universe, a circular temple which he dedicated to Vesta and in which the sacred fire was kept; and he observes that this was in accordance with the opinion of some of the Pythagoreans, who maintained that the proper seat of fire was the centre of the universe, for the reason mentioned by Aristotle. It does not appear that the Pythagoreans imagined the central fire to be the sun, or that the earth and planets revolved about that luminary; but it is distinctly stated by Aristotle that they conceived the movement of the earth about the centre to be the cause of the succession of day and night, which seems to shew that the earth was supposed to perform the revolution in that time. Ἐναντίως οἱ περὶ τὴν Ἰταλίαν, καλούμενοι δὲ Πυθαγόρειοι, λέγουσιν· ἐπὶ μὲν γὰρ τοῦ μέσου πῦρ εἶναι φασι, τὴν δὲ γῆν, ἓν τῶν ἄστρων οὖσαν, κύκλῳ φερομένην περὶ τὸ μέσον, νύκτα τε καὶ ἡμέραν ποιεῖν [a].

Whether the centre here spoken of is that of the earth itself or of the region of fire is uncertain; if the former, which seems to be implied in the expression that a revolution about it is the cause of day and night, it would follow that the earth was supposed, at least by some of the Pythagoreans, to be stationary in space, though situated at a distance from the centre of the universe. That such a supposition was entertained is well known, for, according to Plutarch [b], Heraclitus and Ecphantes described the earth as moving without changing its place, which, however, may either refer to the diurnal rotation, or to the continual descent before mentioned; and Cicero relates [c] that Nicetas of Syracuse considered all the stars to be at rest and the earth alone to be in motion: the same philosopher, he adds, had shewn that the latter, by a movement on its axis, produced the same appearance in the heavens as would be observed if these were in motion and the earth at rest. As early, probably, as

[a] Aristotle, De Cœlo, Lib. II. cap. 13.
[b] De Placitis, Lib. III. Cap. 13.
[c] Quæst. Acad. Lib. IV. sect. 39.

the time of Pythagoras, the doctrine of the earth's diurnal revolution appears to have been maintained in India[a]; for Brahma-Gupta, quoting the words of Aryabhatta, a very ancient astronomer of that part of the world, says "The sphere of the stars is stationary, and the earth making a revolution produces the [apparent] daily risings and settings of the stars and planets"; and though Brahma-Gupta endeavours to impugn the sentiment, asking why, if the earth revolves, objects on its surface do not fall away from it, meaning perhaps, when by the revolution, they arrive under their former place; yet another and subsequent commentator, who seems to have lived about the eleventh century, justifies the opinion of Aryabhatta on the ground that the under part of the earth is by turns the upper; and that wherever the spectator stands, on the earth's surface, that spot is the uppermost point.

In the dialogue entitled Timæus is contained an ample development of the ideas of the "divine Plato" concerning the nature of the universe which, as they seem to have been more ancient than the notions ascribed to Pythagoras, and to have prevailed very generally among the Greeks long after the times of these philosophers, it will be proper to present here in an abstracted form. Timæus is made to say that the Divinity, or the Supreme Intellect, composed the universe of fire and earth, in order that it might be both visible and tangible, but, because two things in nature, he observes, cannot exist without the intervention of a third, water and air were created and placed between the two former elements: taking this account in connexion with a passage in Plutarch[b], where it is stated that Plato considered the earth to be in the centre of the system, it will be evident that Timæus conceived the elements of water, air and fire to recede from the earth as a centre in the order of their densities; while, according to the Pythagorean hypothesis, fire, as we have said, was supposed to occupy the centre of the universe: this latter was, no doubt, a sort of heresy which arose out of the older system, and was, certainly, embraced by few persons though Plutarch[c] quotes a passage from Theophrastus to shew that

[a] Asiatic Researches, Vol. XII

[b] De Placitis, Lib. II. cap. 15.

[c] Quæst. Plat., sect. VIII.

Plato in his old age adopted it, and admitted that the centre ought to be appropriated to some more noble element than the earth, or rather, than terrestrial substance. Timæus adds, that the Divinity gave to the universe a spherical form, observing that, as it was to contain all beings within itself, its most convenient figure was that which contains all figures within its own; meaning, perhaps, the regular geometrical bodies, which may be inscribed within a sphere[a], or that a sphere contains the greatest volume within a given surface. The opinion of the annual revolution of the earth, if indeed it be true that this was meant by Aristotle, may naturally enough have arisen out of the idea that the earth was not in the centre of the system; since, on that supposition, it would seem to have an analogy with the planets, which are observed to revolve about some central point: it is generally believed to have been first professed in Italy by Philolaus, one of the disciples of the Pythagorean school, who lived about ninety years later than its founder; and according to Plutarch he, like Anaxagoras, suffered persecution for this doctrine, which shocked the prejudices of men, in those days, so much as to subject the person who maintained it to the imputation of perversely opposing the dictates of what was then considered as common sense, and cause him to incur the suspicion of impiety. Philolaus is said to have resided in Italy and to have composed a work on the universe which Plato, who made a voyage to that country for the purpose of conversing with him, introduced in the Timæus.

To the Pythagoreans was ascribed the opinion, that diametrically opposite to our earth, with respect to the centre of the system, was another earth which they called the Antichthone; it will be difficult to imagine from whence this remarkable idea could have been taken if it did not arise from a misconception of some expression used by Pythagoras to designate the Antipodes, in which sense it is used by Pomponius Mela[b]; or to designate the moon herself, as we find it to have been in the commentary of Proclus on the Timæus. But, if we are to understand the word as signifying, according to the general opinion, an invisible body accompanying the earth in its revolution, we can only

[a] Proclus in Tim., Lib. III. [b] Lib. I.

suppose it to have originated in the notion that when one body revolves about a distant centre, another body is necessary, on the opposite side of the centre, to produce an equilibrium with the former like that which takes place when two bodies connected together by an inflexible bar are made to turn on a fulcrum situated between them. Democritus of Abdera, who lived about 450 years before Christ, and whom Seneca designates as the most subtle of all the ancients, is said by this writer,[a] to have conjectured that there were many bodies circulating about the centre of the universe but invisible to us, on account either of the obscurity of their light or the positions of their orbits; he ascribes the same opinions to Artemidorus, and from the last expression it may be suspected that these bodies, like the Antichthone above mentioned, were conceived to keep always behind or opposite to that hemisphere of the earth which was then unknown, during the revolution of the latter: but there is not the least ground to support the opinion of Sir W. Drummond, that they were the satellites of Jupiter and Saturn which, by means of the telescope, and he endeavours to prove[b] that this instrument was known to the ancients, he supposes the Greeks, Chaldeans and Hindus to have discovered.

Some of the ancients seem not to have been aware that there might be day-light in one hemisphere of the earth while darkness prevailed in the opposite, and imagining that all the earth must be enlightened at one time, they appear to have entertained an opinion that, for this purpose, each hemisphere had its particular sun and moon. The Jainas in India[c] are said to have imagined the existence of two suns, as many moons and a double set of planets and stars, which they supposed to revolve about the pyramidal mountain occupying the middle of the earth: and such notions are, probably, the foundation of the opinion ascribed by Plutarch to Xenophantes[d] that there existed a plurality of suns and moons. Cleomedes mentions, also, an opinion that the number of planets was infinite of which, he observes, five only could be seen by us, those invisible planets appear, like the *Rahu* of the Hindus, to have been considered

[a] Nat. Quæst. Lib. VII. cap. 3 & 13.

[b] Origines, Book IV. Chap. 6.

[c] Asiatic Res. Vol. XII.

[d] De Placitis, Lib. II. Cap. 24.

as the causes of the eclipses of the moon; a notion alluded to by Lucretius[a] and which was, certainly, maintained in the infancy of astronomy. But it is an important circumstance in the history of the science that, before the time of Plato, the opinion that both hemispheres were successively enlightened by the revolution of the earth on its own centre, or axis, was very prevalent; in proof of which it may be alleged that it is referred to in the Timæus; and Aristotle expressly asserts that some persons admitted this notion though they considered the earth to be situated at the centre of the universe.

The disciples of Pythagoras are said also to have entertained the opinion that the fixed stars are, like our sun, the centres of systems of planets; and it is added that some of those persons considered the comets, not as meteors formed in our atmosphere, which was the general notion, but as planets subject to the sun's influence and revolving about him. No dependence, however, can be placed upon such assertions, and many of the opinions which have been ascribed to the members of that school, undoubtedly, originated in a much later period.

Pythagoras is alleged, probably with truth, to have adopted the notion of Anaxagoras that the moon was inhabited; and we learn from Plutarch[b] that he endeavoured to prove the lunar plants and animals to be more beautiful, and fifteen times as large as those of the earth This is, indeed, a romance worked up in the spirit of the adventurous philosopher who, in the language of Dr. Chalmers, "leaving the sobriety of experimental science, by vague and general analogies, makes a loose application of the natural history of the earth to that of the planets, and shifts his speculations from thence to the character of their inhabitants, availing himself of some slender correspondence between the heat of the sun and the moral temperament of the people it shines on:" in which, as the same elegant writer observes, "he is evidently expatiating on the field of imagination and is venturing on a dark unknown where the wisest philosophy is silence." Plutarch ascribes to Pythagoras the idea that the lunar nights are fifteen times as long as those of the earth; which, if understood to mean fifteen durations of our day

[a] De Rerum Naturâ, Lib. II   [b] De Placitis, Lib. II. Cap. 30.

and night, would seem to shew that he was aware of the period in which the moon revolves on her axis, this is, however, doubtful, and it is more probable that the length he has assigned to the lunar night was obtained from some one of the fanciful analogies in which the learned men of that age and country were so much accustomed to indulge.

Another remarkable doctrine which appears to have been held by Pythagoras, or by some of his earliest disciples, is that the celestial spheres, during their revolutions emit musical sounds of various intensities according to their distances from the earth, all which, however, were supposed to be inaudible to men[a]. Now, according to Plutarch[b], the interval from the earth to the fixed stars being, by these philosophers, considered as the Diapason or extent of seven tones, the distances of the seven planets, including the sun and moon, from each other, were expressed by tones and half tones in different proportions, and there can be little doubt that, by this harmony of the spheres, they only meant to express the order supposed to prevail in the disposition of the several bodies which constitute the universe: Dr. Gregory[c], however, draws from the idea a proof that the Pythagoreans were acquainted with the Newtonian law of the decrease of gravity He observes that these philosophers have veiled their doctrine under an allegory when they assert that Apollo touched a seven-stringed lyre, which he supposes, agreeably to an idea of Macrobius[d], to represent the sun and seven planets, and to indicate that the former retained the latter in their orbits by attractive forces in harmonic proportion; and, because the tones obtained from cords equally thick but of different lengths are inversely proportional to the squares of the lengths of the cords, he infers that the harmonic proportion alluded to, in the attractive forces, is the inverse duplicate of the distances of the planets from the sun. Nevertheless few persons will, we imagine, be inclined to believe that the doctrines of Pythagoras, or of any of his disciples, lay so deep as is here supposed.

While the science of astronomy was spreading towards the

[a] Censorinus, De Die Natali, cap 13

[b] De Musica.

[c] Astronomiæ Elementa.

[d] Macrob. Sat. I 19

West by the labours of those persons who were educated in the Crotonian school, it continued to be cultivated in the states of Greece; where, about one hundred years after the time of Pythagoras, Democritus of Abdera made himself celebrated by his efforts to assign a physical cause for the origin of the universe. This philosopher, whose notions appear to have been subsequently adopted by Leucippus and Epicurus, and are fully developed in the poem of Lucretius [a], and whose system of nature resembles, in some respects, that of Descartes, is said by Aristotle [b] to have taught, that innumerable atoms, coming from every part of space and striking each other obliquely, formed vortices in which the lighter particles ascended towards the surface, or upper regions of each vortex, while the more gross concreted together about the centre, and thus constituted the sun, planets and earth; the latter he supposed to remain at rest in the central vortex where it was formed, but the others were conceived to revolve about it at various distances, the nearer planets moving with less velocity than those more remote.

That astronomical observations were occasionally made at this time in Greece, and that they were registered and compared together for the purpose of regulating the calendar, and perhaps, of forming tables of the movements of the sun and moon, is rendered probable by the consideration that the lunar cycles now began to be employed in that country in order to make the festivals which depend upon the moon fall in the same season of the year, and to render their commencement an epoch from whence the times of the observed phenomena of the heavens might be reckoned. The Philolaus above mentioned is stated to have invented a cycle of fifty-nine years which he called a great year and in which he said were contained twenty-one intercalary moons [c]. It is uncertain by what estimate of the length of the solar year and of the time of a lunar revolution he formed this period, but, if he considered the first as equal to 365 days, and the latter to 29.75 days, there will be about 729 complete lunations in that number of years, and then, the lunar year being equal to twelve such lunations, there must be added

[a] De Rerum Natura. [b] De Cœlo, Lib. I.
[c] Plutarch. de Placitis, Lib. II. cap. 20.

twenty-one of these to make the number in 59 lunar years equal to the number in 59 solar years, and it is not improbable that the cycle may have been so determined.

It appears from Diogenes Laertius[a] and Censorinus[b] that either Cleostratus or Eudoxus was the author of the Octaeteris, or cycle of eight solar years, but it is easy to conceive that, from its simplicity and inaccuracy, it is likely to have been in use before the times of those philosophers; and we conclude, therefore, that its invention may with propriety be assigned to the age of which we are speaking. According to Geminus, the period consists of 2922 days, and contains very nearly 99 months, or synodical revolutions of the moon, he says each of these was estimated at $29\frac{1}{2}+\frac{1}{33}$ days, (29.5303 days,) and that ninety-nine such months are equal to $2923\frac{1}{2}$ days; which, therefore, exceed the above value of 8 years by one day and a half. Considering, consequently, the lunar year to consist of 12 months, or 8 lunar years to consist of 96 months, they intercalated, in each octaeteris, 3 months; in order to make the lunar calendar agree with the solar: the error of one day and a half must, however, have remained, and this, in 160 years, must have amounted to about one month[c].

But the most famous cycle of antiquity is that which was invented, or improved, and promulgated by Meton and Euctemon, at Athens, and which began to be employed on a day corresponding to the 16th of July in the year 433 Before Christ. From a passage in Ptolemy's Mathematical Syntax[d] we learn that, according to Hipparchus, in his work on *Embolismic Months and Days*, (since lost,) the above philosophers had found, by observing the epoch of a solstice at Athens in the year 316 of Nabonassar, or 430 Before Christ, and comparing it with one of more ancient date, the length of the solar tropical year to be $365+\frac{1}{4}-\frac{1}{76}$ days, or 365.2368 days, and, assuming the duration of a synodical lunar revolution to be 29.53 days, Meton is said to have found that 19 solar years contained 235 lunar revolutions, or 19 lunar years together with 7 intercalary revolutions; the lunar year being understood to be equal to twelve revolu-

[a] Lib VIII

[b] De Die Natali, cap. 18

[c] De Apparentius Cœlestibus, cap. De Mensibus.

[d] Lib. III.

tions, or 354.358 days This cycle of nineteen years, which is called by the name of its inventor, has been ever since his time employed for the regulation of the public festivals depending upon the moon: it is found in the astronomical works of the Arabians and Hindus; but whether either of these people received it from the Greeks, or the Greeks from the Hindus, or whether it was the result of independent observations made by either people, it is impossible to determine. The arrangement of the calendar, according to Meton was, that of the 235 months of the cycle, 110 months should have 29 days each, and the remaining 125 months, 30 days each, but as this number of days exceeds the length of nineteen solar tropical years by about one quarter of a day, at the end of four times nineteen years, or 76 years, the excess amounts to one solar day and the cycle soon became erroneous. To remedy this evil Calippus subsequently quadrupled the former cycle, and proposed another of 76 years, at the end of which time one day was to be omitted: this cycle began to be employed in the year 330 Before Christ, and it was expected that it would produce an exact agreement between the calendar and the seasons; but the values assigned to the solar and lunar years not being quite accurate, such is not the fact, the error thence arising in the course of many ages, is found, however, to be of small amount.

CHAPTER IX.

CELESTIAL SPHERES IMAGINED BY THE GREEKS.

The constellations described by Eudoxus —Uncertainty of the positions assigned by this philosopher to the equinoctial points —Probability that Eudoxus made observations with instruments.—The system of concentric spheres supposed to have been invented by him.—Dispositions and movements of the planetary spheres according to Eudoxus.—The number of spheres increased by Calippus —Nature and general laws of the motions of concentric spheres —Investigation of the planetary orbits recommended by Plato. His disposition of the orbits —The eternity of the universe asserted by Aristotle.—His opinion that the planets move with equal velocity.—His estimated magnitude of the earth and sun.—He augments the number of planetary spheres.—Celestial observations made by Pytheas —Opinions of the ancients concerning the tides

About sixty years after the adoption of the Metonic cycle a description of the face of the heavens and a system of the universe appear to have been made public by Eudoxus of Cnidos, who lived about 370 years before Christ and was certainly one of the most celebrated mathematicians of his time, since he is acknowledged to be the author of one of the most important books in that collection of the elements of Geometry which is ascribed to Euclid. The astronomical works composed by him are lost, but one of them, which seems to have contained a description of the constellations, was paraphrased by Aratus about one hundred years after his time in a poem still extant: from this it appears that the constellations into which the heavens were then divided were nearly the same as those represented on our present celestial globes. It is found, however, that the relative positions assigned by Eudoxus to the fixed stars present very numerous discrepancies, and it has been attempted to explain them by supposing that the philosopher had copied the places of the stars from registers of ancient observations, which, having been made at different times, could not agree with each other on account of the movement of the equinoctial points in the intervals; but the irregularity of the errors is so great as to render it impossible to avoid concluding that the places of the stars were estimated by the eye alone, and without any attempt at

precision. Aratus remarks, and his observations may be considered as those of Eudoxus himself, that the stars revolve regularly, meaning with equal angular velocities, because they are permanently fixed in the celestial sphere; but he adds, there are some among them, meaning the planets, which change their places, performing revolutions and returning to conjunction in the same part of the heavens at the end of various intervals of time, and he directs that their places should be observed by referring them to the fixed stars which they occasionally approach. From this precept Delambre concludes that the Greeks then possessed no instruments for determining the longitudes and latitudes of stars, and that they were almost entirely ignorant of any theory of the planetary movements: both these consequences, however, do not necessarily follow, for it is possible that Eudoxus may have used instruments though Aratus has not noticed any observations made with them, which might be because such details do not form fit subjects for a poem.

It would be desirable to ascertain, if possible, from the work of Aratus, the position which Eudoxus assigned to the equinoctial or solstitial points, in order that the subsequent movement of those points might be determined with precision; or, assuming this to be known, that the time might be found at which the observations were made from whence the position so assigned was discovered; but it is to be regretted that the description he has given does not enable us to arrive at any satisfactory conclusion on either of these heads. Eudoxus mentions particularly the two tropics and the equator, observing, as is related by Hipparchus in his commentary on Aratus, that the northern tropic touches the zodiac in, or about the constellation Cancer, and that the southern tropic cuts the middle of Capricornus: hence he must have supposed the equinoctial colure to pass through the middle of the constellation Aries. But the difficulty is to ascertain where is the middle of that constellation; for if we suppose its whole extent to be equal to 30 degrees, the value now given to it, and that it commenced with γ Arietis, which is the first remarkable star in it, and whose longitude is at present equal to about 30 degrees, since the equinoctial colure passes near α Andromedæ; it would follow that the precession

in the interval between the time in which we live and that indicated by the above position of the same colure, is about 45 degrees; which, at the known yearly rate of precession, would place the epoch of that position at above 3200 years since. Or, since Ptolemy makes the difference of longitude between the two stars which he considers as the first of Aries and of Taurus respectively, probably those marked γ and δ in Aries, to be equal to 18 degrees only; if this be taken for the extent of the constellation, the precession, since the time when the colure was in the middle point between these stars, would be 39 degrees, which places the epoch of that position at about 2800 years since, or about 970 years before Christ; and according to Geminus, who lived 300 years after Eudoxus, it appears that the latter philosopher placed the vernal equinox in the sixth degree of Aries which, if the star γ be taken for the first in the constellation, would bring the epoch to the year 750 Before Christ: now it is not impossible that, by observations made at one of these periods in Egypt or Chaldea, the vernal equinox might be found to be situated about the middle of the constellation, and Eudoxus, being ignorant of the precession, may have supposed it to occupy the same place in his days, but this situation is completely at variance with that deduced from the position assigned by Eudoxus to the stars Castor and Pollux, both of which, according to Hipparchus, he placed in the solstitial colure: now the longitude of Pollux is known to be $2^s\ 20^\circ\ 44'$ greater than that of γ Arietis, therefore the equinoctial point should, if the former star were in the solstitial colure, be $9^\circ\ 16'$ westward of the latter star; and, as this was its position about 700 years after the time of Eudoxus, there must consequently be some great error either in the work of that astronomer or in the paraphrase of Aratus, from whence Hipparchus drew the notice concerning the place of Castor and Pollux. The last mentioned philosopher, who has pointed out this mistake, observes also that Eudoxus has committed another error in saying the stars of Aries are too small to be visible at the time of full moon, whereas three of them are then very distinguishable; and Delambre, apparently with good reason, considers these circumstances as proofs of inaccuracy, but M.

Bailly endeavours[a] to account for them by supposing that the first of the zodiacal constellations, in the time of Eudoxus, commenced as in the Hindu astronomy at a point situated 13 degrees westward of the circle of longitude passing through γ Arietis. Now it will be found, by computing backwards with the received value of the precession that, in the time of Eudoxus, the equinoctial colure passed through γ Arietis, and it would follow, agreeably to the supposition of Bailly and the statement of Eudoxus, that the colure was then situated about the middle of the constellation. but the hypothesis of the French astronomer will carry him no further; on the same supposition it will be found that the star Castor was, in the time of Eudoxus, situated, in longitude, about ninety degrees eastward from the origin of the zodiac; and Bailly conceives that this may have induced him to consider it as in the solstitial colure though, in reality, it must have been about 13 degrees from it The remark of Eudoxus concerning the invisibility of the stars of Aries admits of no better explanation, for Bailly evidently supposes that the constellation which the Greek astronomer calls Aries coincided with that now called Pisces which, certainly, contains only very small stars, yet, since γ Arietis is made the middle point, it is clear that the three principal stars of Aries must be included in the same constellation.

The intention of Bailly is to prove that the astronomy of Eudoxus was derived from India, but the circumstances above stated will scarcely be considered as favourable to the opinion, and, even if it should be admitted that a zodiac, whose commencement is in the situation above supposed, was ever received in Europe, it would be equally probable that it came from Chaldea or Egypt; from whence also it might have found its way to India, where it has ever since continued in use, while, in this part of the world, a new origin of the constellations may have been chosen soon after the time of Eudoxus. Among the ancient Persians the commencement of the zodiac appears to have corresponded with that which so long prevailed among the Greeks, and, no doubt, both people received their astronomy from the same school.

[a] Astronomie Indienne, Chap. X. sect. 4—10.

We have given some account of the means which may have been originally employed to divide the ecliptic into signs for the purpose of designating the longitudes of stars: but as it can hardly be denied that Eudoxus made use of instruments in determining the times of the equinoxes and solstices, it may be proper here to observe that some light has been thrown upon the manner of distinguishing the places of celestial bodies, by the translations lately made of the astronomical works of the Hindus; for it is probable that the practice of this people, at the time when the science flourished among them, was nearly the same as that which was pursued more anciently in other parts of the East. Mr. Colebrook, in a paper on the Hindu division of the zodiac, having shewn that the ancient natives of India, in finding the longitudes and latitudes of stars with circular instruments, made use of a circle of declination instead of a circle disposed perpendicularly to the ecliptic, and caused its plane to pass through the star whose situation was required; concludes that the longitudes were reckoned, on the ecliptic circle, from the equinoctial point to the intersection of the circle of declination with the latter circle, and that the latitudes were reckoned on the circle of declination from the ecliptic to the star[a]. This method of observing, if we may be allowed to suppose that it was practised by Eudoxus and other Greek astronomers down to the time of Hipparchus, will permit us to consider that, more anciently, the equator, only, was divided into twelve equal parts, or signs; to accomplish which by means of the Clepsydra would be a much more easy task than that of so dividing the ecliptic, and we may then admit that the divisions of the latter circle were but rudely estimated before the invention of trigonometry by Hipparchus. Bailly, indeed, endeavours to shew that the longitudes of celestial bodies were by Eudoxus reckoned on the equator[b], but his proofs are too few to inspire confidence; and, besides the probability of an error in one of the numerals, in the texts of such writers as Geminus and Columella, to whom he refers, it is by no means certain that the stars *α Arietis* and *α Capricorni* were by these authors taken to designate the places of the equinoctial and solstitial points.

[a] Asiatic Researches, Vol. IX. [b] Astr. Ancienne Eclairc liv VI. sect. 11.

That Eudoxus had made some observations on the altitudes of the sun by the gnomon or otherwise, is probable from a remark made by Hipparchus in quoting a work of this philosopher; he observes that the declination of the sun at the times of the winter and summer solstices did not agree with each other, and that the ancients, probably meaning Eudoxus, considered these variations to be owing to certain small deviations of the sun, in his annual course, from the mathematical circumference of the ecliptic. According to Hipparchus this deviation of the sun in declination amounted to about five minutes of a degree; and it is true that there is a deviation of the sun from the plane of the ecliptic, which is caused by the attraction of the planets, but its value is far from being so great as that supposed by the Greek astronomer, who has evidently been misled by errors of observation. Eudoxus is said to have been the first of the Greeks who discovered that the moon's orbit was inclined to the ecliptic, and that the points of her greatest latitude were subject to a movement contrary to the order of the signs[a]; but we have already shewn how the latter fact may have been ascertained by means of a register of the solar and lunar eclipses; and, therefore, it is probable that this philosopher was merely the first who determined the elements of the lunar orbit by instrumental observations.

The circumstance which has given particular celebrity to the name of Eudoxus is the alleged invention of the system of concentric spheres by whose movements it was attempted to account for those observed in the planets. It is easy to conceive that a movement which appears to take place in any direction, while the moving body seems to remain always at the same distance from the observer, would be immediately explained by considering the body to be attached to the surface of a material sphere revolving on an axis. If the motion of the body should appear to take place in a plane which is not perpendicular to the supposed axis of the sphere's motion, it might be still represented by supposing the sphere to which the body was attached to be, itself, contained within another, this within a third, and so on; each spherical shell being endowed

[a] Simplicius, Comment. 46, Lib. II. De cœlo.

with a motion peculiar to itself and being capable of communicating its motion to the next, by which means the attached body would appear to be carried in some direction oblique to that produced by the proper motion of the sphere to which it belonged: and in this manner Eudoxus proposed to explain the motions first observed in the sun, moon and planets.

It appears that, in its most simple state, this system required three spheres for each planet, and one sphere, denominated the Primum Mobile, was supposed to enclose the whole, of which the earth was the common centre; and, as the planets are at different distances from the earth, it was necessary to consider the spheres as transparent or of a crystalline nature in order to permit the remoter planets to be seen through the spheres of those which are nearer.

Perhaps, at the first view of the heavens, it may have been supposed, as was observed in Chap. V., that the sun, moon and stars were attached to the concave surface of one material and revolving sphere, but the variety of movements in the planetary bodies must have soon suggested the notion that these, at least, were moved independently of each other and of the rest, and it is probable enough, from a passage in Aristotle [a], where it is affirmed that the Egyptians and Chaldeans understood the planets to be at different distances from the earth, and in Plato [b], where the philosophers of Chaldea and Egypt are said to have maintained that the eighth sphere turned with the diurnal rotation only, that, among these people, originated the opinion that each was attached to a separate sphere by whose movement it was carried about the earth. In the time of Eudoxus the nature of the more ancient planetary systems may have been well known: whether or not they were similar to that which is attributed to the Greek philosopher no evidence remains to shew; but we may safely allow that the latter is entitled to the merit of having adapted a system of spheres to the state of astronomy in his time, and perhaps, of being the first who introduced to the Greeks that mode of representing the phenomena of the heavens.

The most ancient accounts we have of the disposition of the planetary spheres, are contained in the works of Aristotle and

[a] De Cœlo, Lib II. Cap. 12 [b] De Republica, Lib. X.

of his commentator Simplicius: from these we find, that each sphere carried the poles of that which was next to it, towards the interior; that the former always communicated its movement to the latter, to produce either an acceleration or retardation in the motion of the planet, according as the two spheres moved in the same, or in opposite directions; but that the inferior communicated no motion to the superior sphere: and that all the spheres were supposed to be in contact. It seems to have been remarked, that the times in which the diurnal motions of the sun and moon were performed, were something longer than that in which the like motion of the fixed stars was accomplished; hence, a particular sphere was thought necessary for each of those luminaries; and as, probably, the like retardation was supposed to take place in the diurnal movements of the planets, each of these was, for the same reason, furnished with a particular sphere in order to produce that movement. The revolution of each of these spheres was supposed to be accomplished about the axis of the earth's equator, and its velocity was supposed to be equal to that of the general sphere of the fixed stars, though the motion it produced in the planet to which it belonged was less, on account of the retardation caused by the contrary motion of the second or next interior sphere, which was imagined to turn on the axis of the ecliptic. Some doubts seem to have been entertained by the ancients concerning the directions in which the proper motions of the sun, moon, and planets took place; for it is observed by Geminus [a], that certain persons, unwilling to admit the existence of contrary movements in the celestial spheres, conceived the motion from west to east to be only apparent, and the real motions of those celestial bodies to be directed from east to west, like that of the sphere of the fixed stars: supposing that, on account of the superior velocity of the latter sphere, the erratic bodies remained behind and, consequently, seemed to recede from the others in an opposite direction. The opinion, however, is opposed by Geminus, and is, plainly, inconsistent with the movements ascribed to the planets in the systems of the later Greek astronomers; yet it appears to have been admitted

[a] De Apparentiis Cœlestibus, Cap. De Motu Planetæ.

by Ptolemy, who asserts [a] that the motion of the Primum Mobile, which is directed from east to west, is communicated to the different spheres (of the planets). In a later age, notwithstanding the increased complexity of the celestial machinery, we find the idea of a movement in the same direction still retained; for Alpetragius observes, that all the movements which are proper to the planets are modifications of that of the Primum Mobile, or sphere of the fixed stars: he adds, that the power of motion exists, essentially, in the latter, and is imparted to the other spheres, becoming weakened as these approach the centre of the system; and thus the planets seem to have a proper motion, from west to east, which is greatest in those nearest to the earth, because they lose more of the force of the Primum Mobile.

Simplicius states [b] that Eudoxus and the philosophers who preceded him, probably the Chaldeans or Egyptians, supposed the sun to be influenced by three movements. The first was directed from east to west, or, as we have said, in the order of the diurnal revolution of the fixed stars and about the same axis, which was considered fixed in space; and this caused the daily rising and setting of that luminary. The second movement was in a contrary direction, or from west to east, by which the sun was carried in one year through the signs of the zodiac, or, as they were then called, the twelve animals; the axis of revolution being perpendicular to the ecliptic and performing a conical movement, in the same time, about the axis of the equator, by which the sun is made to change his place of rising and setting, daily, agreeably to the observed phenomena. These two spheres probably, at first, sufficed to explain the solar movements, but Simplicius observes that, since the changes of the sun's declination are not performed in precisely the same time as his revolution in longitude, a third sphere was found necessary. Now there is no reason to believe that the real movement of the equinoctial points and the real change in the obliquity of the ecliptic were known in the days of Eudoxus, but solsticial and equinoctial observations made with imperfect instruments appear to have given rise to an opinion that the sun's greatest

[a] Almagest. Lib XIII. Cap. 2.

[b] Comment. 46, Lib. II De Cœlo.

declination and the time of his arrival at the equator were both variable, and it seems to have been the office of the third sphere to represent this pretended inequality. Its axis was supposed to have a small inclination to that of the ecliptic, and the extremities of that axis, which were attached to the second sphere at a distance from the poles of the latter equal to the excess of the greatest observed declination of the sun from the equator above the mean declination, were carried with it in small circles about those poles while the sphere itself performed annually a revolution on its axis in retrograde order: thus the sun, which was imagined to be attached to this third sphere, would appear to describe a path not coinciding with the ecliptic, but crossing it in two points diametrically opposite to each other, and deviating from it as much as the excess above mentioned; these intersections being carried in retrograde order through the circumference of the ecliptic, it would follow, that the restitutions of the sun's declination take place in less time than the annual revolution of the sun in longitude is performed; which was supposed to be conformable to observation.

The lunar system of Eudoxus was nearly similar to the solar; for he assigns to the moon three spheres of which one, as Simplicius shews in the work above quoted, revolved in the same manner as the fixed stars; the second revolved from west to east about the axis of the zodiac and carried the poles of the third, which were distant from its own as much as the moon's greatest latitude. By the first of these spheres the diurnal motion of the moon was produced; and by the second was exhibited both her direct monthly revolution in longitude and the retardation of her diurnal motion with respect to that of the fixed stars. The moon herself was attached to the third sphere and thus was carried by the motion of the second along her apparent monthly path, obliquely to the ecliptic, so as to produce the daily changes of her latitude: but the third sphere performing in eighteen years a revolution on its axis in retrograde order, the nodes of the moon's path were in that time carried through the circumference of the zodiac, in the same order, agreeably to observation.

Aristotle shews[a] that Eudoxus gave to each of the planets

[a] Metaphysica, Lib. XII. cap. 8.

four spheres, of which the first and second were similar in position and movements to the first two spheres of the sun and moon: for the exterior sphere of each planet revolved daily like that of the fixed stars from east to west, but with less velocity on account of the retardations caused by the contrary movement of the second sphere. The axis of the latter was supposed to coincide with that of the zodiac like the axis of the corresponding sphere in the systems appertaining to the sun and moon; and this sphere also revolved from west to east, but in the times employed by each planet to describe the circumference of the zodiac: thus, he observes, the stars of Mercury and of Lucifer, [Venus] which appear always to accompany the sun, are carried round in one year, the star of Mars, in two years; of Jupiter, in twelve; and of Saturn, in thirty The other two spheres belonging to each planet were intended by Eudoxus to produce the alternately direct and retrograde movements exhibited by all the planets, and appear to have been disposed in the following manner: the axis of the third sphere lay in the plane of the ecliptic, by which means the movement of this sphere was perpendicular to that of the second, so that if a star had been placed on any part of the surface of this sphere except in either of its poles, it would have appeared to describe a circle about its poles, and to be alternately above and below the ecliptic while it was carried through its circumference by the motion in longitude, by which means it would have been subject to greater changes of latitude than are consistent with the observed phenomena: in order, therefore, to remedy this imperfection and, at the same time, produce the alternately direct and retrograde movement, it was necessary to employ a fourth sphere which was made to revolve upon an axis inclined to that of the third sphere, and in a direction contrary to that of the motion of the latter, but with twice its velocity.

Now, if the pole A (Plate I. fig. 1.) of the fourth sphere be brought into the plane of a great circle, as B A, passing, perpendicularly to the ecliptic C D, through E, the pole of the third, and if a star be then situated on this fourth sphere, immediately under the last mentioned pole, since the angular movement of the star at E about the pole A, is twice as great as that of A about

the pole E, and in a contrary order, it will follow that when A has moved through any arc, as A A′ the star under E will have moved to E′, and this point will be in the plane of the ecliptic because the angle E A′E′ is double the angle A E A′, or its equal E A′e, formed by drawing A′e perpendicularly to C D. And it is evident that, the distance of the star from A being equal to that of the poles A and E from each other, the star will be always in the circumference of the ecliptic so as to appear from the earth to move, alternately in direct and retrograde order, to equal distances on either side of the pole of the third sphere, the extent of the arcs of motion depending upon the distance between the two poles. In the case here assumed the planet would appear to have no latitude, but if the distance of the star from the pole of the fourth sphere were greater or less than the distance of this pole from that of the third sphere, the planet would experience continual changes of latitude, and would be in the ecliptic twice only, in one revolution of the pole of the fourth sphere. The times in which the retrograde and direct movements are performed, are not, however, equal, either in this or in the former case, because the velocity of retrogradation is only equal to the difference between the velocities of the star and of the pole E, and that of the direct movement is equal to their sum. With respect to the inferior planets, the periods assigned by Eudoxus to the revolution of the third sphere are, for Venus, nineteen months, and for Mercury, 110 days; being nearly the times which elapse between two inferior or two superior conjunctions with the sun: and, if the pole of the third sphere be supposed to correspond with the place of the sun, it is evident that the machinery above described will represent, though rudely, the apparent deviations of those planets from, and their returns towards that luminary. But, with respect to the superior planets, the periods he has assigned to the revolution of the third sphere are, for Mars, eight months and twenty days, and for Jupiter and Saturn, each, three months and ten days; these periods cannot be so easily explained, but, probably, they relate to the times in which the arcs of direct or retrograde movement were supposed to have been accomplished by those planets respectively. Thus, as Simplicius observes, the whole number of spheres

imagined to exist, in the time of Eudoxus was twenty-seven, but these were usually considered as eight spheres because the three belonging to the sun, the three to the moon, and the four to each of the five planets, were respectively reckoned as one and there was, besides, the sphere of the fixed stars.

But some of the inequalities of motion arising from the ellipticity of the orbits of the planets, and from their mutual attractions, could not fail to be discovered in proportion as observations became multiplied and more accurate, and it was found necessary to imagine new spheres in order to represent these variations; this, it appears, was attempted by Calippus who, as Aristotle relates in the twelfth book of his Metaphysics, added two spheres to the three which had been given by Eudoxus to the sun; the same number to the system of the moon, and one to that belonging to each of the two inferior planets. The four spheres which Eudoxus had given to each of the superior planets were supposed sufficient to explain their movements, and thus, the whole number of spheres including that of the fixed stars was thirty-three. Aristotle distinguishes these into Astriferas and Anastros; and he observes that of the former there are eight and of the latter, twenty-five. The Astriferas, or those spheres bearing stars, must have comprehended that of the fixed stars and the seven to which the planets were attached; and the others must have been those employed to give movement to the latter spheres.

The two additional spheres applied to the sun and moon being intended to produce the accelerations and retardations of motion observed in those celestial bodies when in perigeo and in apogeo, respectively, were probably situated within the three former, similarly to the interior spheres assigned to each of the five planets by Eudoxus: that is, the axis of the fourth might lie in the plane of the ecliptic, so that the revolution of this sphere might be performed perpendicularly to that plane while its pole was carried along the circumference of the zodiac, in one year for the sun, and in one month for the moon, by the general motion of the second sphere; and the axis of the fifth might be oblique to the former, so that, by giving to this last sphere twice the velocity of the fourth in a contrary direction, the sun or moon which

was attached to it, would be compelled to move in or near the ecliptic, alternately in direct and retrograde order with respect to the pole of the fourth sphere, but, if we suppose the velocity of the revolution of the sphere bearing the luminary to be less than that of the last-mentioned pole, the effect would be that the general movement of the sun or moon received merely an alternate acceleration or retardation; and it is easy to imagine that, by a due adjustment of the places of the poles and the velocities of the spheres, the phenomena of those celestial bodies might, though still incompletely, be represented. The additional sphere given by Calippus to each of the planets Mercury and Venus was, probably, intended to correspond with the third sphere given by Eudoxus to the sun, in order that the pole of the third sphere of each inferior planet might experience the same variations in declination that were supposed to be observed in the sun, the mean place of which was, as we have stated, represented by that pole.

It may be doubted whether the inventor of the system of concentric spheres laid the least stress upon their materiality, though this quality seems, in succeeding times, to have been implied in all popular descriptions of the heavens. There is nothing, however, in the works of the ancient astronomers to shew that their calculations for determining the celestial phenomena were influenced by the hypothesis of material spheres, on the contrary we have abundant evidence from the writings of Ptolemy that their practice was conducted agreeably to the supposition that the orbits of the heavenly bodies existed only in the imagination. The celestial spheres mentioned by Plato, in his dialogue Timæus, probably meant the regions of space in which the planets are placed; he calls them immaterial substances, yet seems to consider them as formed of a species of fire which has the property of giving light without burning; and each sphere is said to be accompanied by gods, demons, and souls of men, all partaking of the nature and properties of the particular spheres to which they belong.

But the Greeks were a nation of reasoners, and their philosophy consisted not so much in analysing the works of nature for the purpose of finding out the hidden causes of phenomena, as

in imagining some first principle and endeavouring from thence to deduce the effects observed. Of this kind is the system of material and concentric spheres, and though it is difficult to divine in what manner they accounted for the first cause of motion or how they supposed that the several spheres communicated their movements to each other; if, indeed, these ever formed the subjects of enquiry; yet we find that, in the days of Aristotle, and probably in those of Eudoxus, they had established certain laws by which they conceived the movements of the spheres to be regulated, and the most important of these may be stated as follow: I. *A sphere can have but one motion about a quiescent axis, and that motion is uniform.* II. *A superior sphere may move an inferior and concentric sphere, but the converse does not hold good.* III. *If two concentric spheres move upon their axes in the same direction, the inferior one has its motion accelerated; the contrary effect takes place if the spheres move in different directions.* These principles are evidently involved, and some of the consequences which flow from them are shewn, in what has been said above concerning the systems of Eudoxus and Calippus; which, as long as they could be made to exhibit with tolerable facility the phenomena of the heavens, were universally admitted, but when their complexity became so great, from the number of spheres necessary to represent the varieties of planetary movement, as no longer to afford repose to the mind, they were abandoned for another which will be hereafter described. It may seem surprising that such means should have been thought of for representing the movements of the celestial bodies; but it must be observed that man always endeavours to resolve a complex effect into one or more simple ones in order to facilitate his comprehension, or render more intelligible the explanations he is called upon to give of it, and the same practice even now prevails among astronomers who, thereby, are enabled to diminish the labour of computing the places of the sun, moon, and planets.

Plato, who was probably contemporary with Calippus, in the dialogue Epinomis, after observing that the science of astronomy is not that which Hesiod and other writers of his day have so denominated, and which relates only to the times of the rising

and setting of stars, has given a detail of the several duties of an astronomer from which we may perceive what, in that age, was considered as such. He is directed to observe the solstices and seasons, the duration of the moon's revolutions and the stars which are seen with the sun; the last expression probably signifying the elongations and oppositions of the planets with respect to that luminary, of which, as well as of the days of the solstices and of the times and circumstances of eclipses, there is no doubt that registers were then kept for the purpose of determining the periodical times of the apparent revolutions of the sun, moon, and planets. What has been just mentioned seems to have constituted nearly the whole of practical astronomy among the early Greeks, but Plato has directed that the philosopher, in the closet, should study the theory of the science, he particularly exhorts him to consider the positions of the eight spheres, and to investigate the revolutions of the seven last under the first, and proposes that he should labour to discover a method of representing by circles all the apparent celestial motions; which may mean that efforts should be made either to improve the then existing system of material and concentric spheres, or to account for the planetary movements by supposing them to be performed in the circumferences of imaginary circles, whether concentric or not. The stationary appearances and the retrograde motions of the planets seem to have been the great impediments to the formation of a satisfactory system of the universe, and a corresponding importance seems to have been attached to the investigations whose object it was to explain them. Ptolemy informs us that, in pursuance of the suggestion of Plato, Apollonius of Perga, who lived about 242 years before Christ, was the first to resolve the problem concerning those appearances and motions; and that he accomplished it by the invention of epicycles, on the circumferences of which the planets were supposed to move while the centres of those moved on the circumferences of the principal orbits. The epicycles afterwards became leading features in the different systems of the universe; in what are called the middle ages they were combined with the material spheres more anciently invented, and the combination produced various systems, equally revolting from their complexity, which succes-

sively prevailed in Europe till the days of Kepler, when the discovery of the true nature of the planetary orbits caused them to be entirely abandoned.

The arrangement of the planets according to the ideas of Plato is exhibited in the dialogue Timæus, where it is stated that the Divinity formed the sun, moon, and five other stars called planets for the purpose of marking the divisions of time; an office which is identical with that assigned to them by Moses, who says they were created for signs and for seasons, for days and for years. These stars are said to have been placed in seven orbits or spheres of which that of the moon is the first or nearest to the earth, and the orbit of the sun, the second; that, as the speaker observes, the heavens might be completely enlightened. Luciferus, or Venus, and Stilbos or Mercury, it is added, were placed in spheres which are endowed with a velocity of motion equal to that of the sun; and this is conformable to the hypothesis of Eudoxus, but it is evident that Plato, like the Egyptians, considered the surfaces of these spheres to be beyond the sun with respect to the earth, for Timæus expressly states that, if placed below the sun, they would cause eclipses, which implies that those planets were then acknowledged to be opaque bodies: such eclipses or transits, as they are called, are phenomena now well known to take place when those planets come between the sun and the earth, but, as they can only be observed with telescopes, the reasoning of Timæus must have, then, appeared conclusive; and it was probably this argument which induced Plato to assign the above mentioned disposition to the inferior planets, in opposition to that supposed by Pythagoras, who, as Plutarch observes[a], like the ancient Chaldeans, placed those planets below the sun. The three remaining planets, Pyroenta, Phaethonten and Phæno, by which epithets Mars, Jupiter and Saturn were designated, follow each other in order, but no explanation is given of their orbits on account, as is stated, of the complexity of the subject: these planets may be said to have been, by all philosophers, placed beyond the sun, and the only exception to the general opinion is that ascribed to Anaximander and Metrodorus who, according to Plutarch[b] assigned the

[a] De Musica. [b] De Placitis, Lib. II. Cap. 15.

highest place to the sun, the next lower to the moon and, under them, the fixed and wandering stars: a similar notion is said to have been entertained by the Hindus, but it is probable that both are to be considered as poetical conceptions rather than the results of philosophical enquiry.

The sphere of the fixed stars, or the inerratic sphere, as it is called, was, Timæus continues, fabricated by the Divinity chiefly of fire and of a spherical form, that it might be splendid to behold and assimilated to the figure of the universe: a circular motion was given to it, but to the stars themselves were adapted two movements; one by which they might all revolve in the same manner, (from east to west daily,) and the other, to carry them forward continually; which has been supposed to refer to the real, or to a fancied motion of precession. These stars were formed, as Timæus supposes, previously to the planets, and he adds that the Divinity created the earth, the common supporter of our existence, the producing cause of day and night, and the most ancient of the gods: this, he asserts, must not be understood as immoveable on the axis of the universe but rather, as endowed with a revolving motion, it is impossible, however, to determine from so brief a description whether by this is meant the diurnal or annual revolution.

The part of the subject which relates to the practice of astronomy, and which would have been the most interesting to us, is omitted by Timæus; who merely observes that, with respect to the conjunctions and oppositions, the direct and retrograde movements of these celestial beings, as he calls the planets, and the times when they become eclipsed, it would be fruitless to attempt an explanation without inspecting their resemblances, this passage, however, is remarkable as it seems to refer to some kind of machine, then in use, for exhibiting the movements of the planets.

The most celebrated disciple of the Academia, or School of Plato, was Aristotle, who pursued his enquiries into every department of nature, and established a system of philosophy which, during nearly two thousand years, continued to be almost the only object of instruction in the schools of Europe and Asia, and was constantly appealed to by the learned as containing a

code of doctrines whose truth admitted of no dispute. He was the author of two works on astronomical subjects, one of which is lost and the other, entitled *De Cœlo*, contains only some general notions, not always just, concerning the form of the earth and the movements of the heavens. In this treatise he endeavours to shew that the universe existed from eternity and is imperishable, but his only argument in support of this position is drawn from an idea that the celestial bodies are endowed with circular motions; from whence he concludes that they are simple substances different from the four elements earth, water, air and fire, and exceeding them in essence and power. Like Plato he, also, designates them animals because they seem to move independently of any sensible or external cause. The circular motion implying an equilibrium between two contrary tendencies to move in the direction of the radii, the ancients saw no reason to believe it could change into any other kind of motion; and since there was no reason to suppose that motion once existing in a particular direction would ever cease when there was nothing to oppose it, the *causa sufficiens* seemed to justify the opinion that the circular motion observed in the heavens would continue for ever: lastly, as no reason can be given why a body at rest should, of itself, begin to move, it was natural to conclude that the universe had existed from eternity in its actual state. Such was the reasoning of Aristotle and, at the present day, we can only refer the origin of the universe, its continuance, and its dissolution, should this last event at any time take place, to the power and will of the Deity.

That the planets moved in circular orbits and with uniform velocities were circumstances universally admitted among the ancients. The Pythagoreans, says Geminus, when first they applied themselves to these subjects, adopted that opinion concerning the motions of the sun, the moon, and the erratic stars; "because, in these divine and eternal bodies no irregularity can exist:"[a] and it will be found from the writings of Aristotle that the notion rested both on the supposed divinity of the heavenly bodies and on the fancied qualities of the circle[b] which, having neither beginning nor end, was considered as the most perfect

[a] De Apparentiis Cœlestibus. [b] De Cœlo, Lib. I. Cap. 2

of all geometrical figures, and on that account, alone proper to represent the celestial movements. But this imagined uniformity of movement was not thought sufficient; and it appears that Aristotle conceived[a] the real velocities of all the planets, in their orbits, to be equal; their different apparent angular velocities being supposed to be caused by the differences of their distances from the earth, the pretended centre of their motions: the only reason given, however, for this opinion is that the planets which are nearest the earth had been shewn by mathematicians to move with the greatest (angular) velocities, and those more remote, with less, *in proportion to their distances.* But the proof must have been imaginary, since the relative distances of the planets were then only known hypothetically. The spherical form of the universe was, also, concluded from the supposition of its perfection and its existence from eternity; for Aristotle argues[b] that the sphere is a perfect figure since it is bounded by one uniform surface, and that it is the most ancient of figures, because that which is perfect is necessarily anterior to that which is imperfect. The sphericity of the moon is more philosophically proved from a consideration of her phases, and, because the moon is round, he concludes[c] that all the other celestial bodies must have the same form.

Aristotle admits the globular figure of the earth, and supports the opinion by those arguments which have ever since been urged on the subject:

> Idcirco terris non omnibus omnia signa
> Conspicimus, nusquam invenies fulgere Canopum,
> Donec Niliacas per pontum veneris oras,
> Sed quærent Helicen, quibus ille supervenit ignis,
> Quod laterum tractus obstant, medioque tumore
> Eripiunt terræ cœlum, visusque coercent[d].

He also asserts[e] that mathematicians have found its circumference to be 400,000 stadia, which was probably ascertained by means similar to those subsequently employed by Eratosthenes and Posidonius, but we are quite ignorant of the length of the stadium by which that measure is expressed. It is remarkable

[a] De Cœlo, Lib. II. Cap. 10. [b] Ibid. Cap 4. [c] Ibid. Cap. 11.
[d] Astronomicon, Lib. I. ver. 215. [e] De Cœlo, Lib. II. Cap. 14.

that he considers the south pole as the highest part of the universe and the north pole as the lowest, but the reason may be that persons inhabiting the northern hemisphere, going towards the equatorial regions where the heat is greater, seem to be ascending towards the sun, the source of heat; and, going northwards, seem to be descending from him. The earth, in accordance with the opinion then generally entertained, that it is an inert mass, and the place to which heavy bodies tend in their descent, he considers[a] as fixed in the centre of the universe, which he supposes to revolve about it. In his treatise *De Meteora*[b], he asserts that the shadow of the earth is conical, assigning as a reason that the sun is the greater body; and, as he states that the distance from the centre of the earth to the vertex of the cone of the shadow is less than the distance of the sun from the earth, it is evident that he must have considered the diameter of the former to be more than double that of the latter. He notices the fact that the moon always presents the same face to the earth, and Plutarch[c] alleges that he conceived her spots to be the image of the ocean represented on her surface as in a mirror. He coincides in opinion with those who have asserted that there may be many other planets, besides the seven then known, and that they revolve about the centre of the universe but are concealed by the earth; and he adds that those planets may be the causes that we have a greater number of visible eclipses of the moon than of the sun, since each of them as well as the earth, may intercept the light of the sun: but this expression, while it betrays considerable ignorance of the celestial motions, yet, demonstrates the fact that the cause of lunar eclipses was, then, well known to the Greeks

In his treatise *De Metaphysica*[d], Aristotle explains his improvement on the system of concentric spheres which had been proposed by Eudoxus and Calippus. According to his commentator Simplicius, for the text is very obscure, he considers that the system of spheres belonging to each planet will, by its connection with that of the next inferior planet, cause the latter system to revolve with a movement equal in velocity and direc-

[a] De Cœlo, Lib II. Cap 14

[b] Ibid Lib I. Cap 13.

[c] De Facie, sect. 2.

[d] Lib. XII. Cap. 8

tion to that which results from the combination of the movements of the spheres belonging to the former system; and thus he conceives that the movement of each planet would be vitiated by that of the next exterior planet; in order, therefore, to counteract this effect he proposes that, on the exterior of the system of spheres belonging to each planet, except Saturn, which being the most remote is not affected by any thing beyond it, there should be another system producing, by the combination of its movements, a motion equal and contrary to that produced by the next exterior system; thus destroying the latter motion and permitting the next interior planet to be moved only by the action of its own system of spheres. The spheres, therefore, which belong to each planet are distinguished by Aristotle into *deferents*, which are those communicating motion to the planet as in the system of Calippus, and *restituents*, which are those employed to counteract the effect of the former on the spheres of the next inferior planet; and he observes that the number of the latter which are to be assigned to each planet must always be one less than the number of deferents, probably because the velocity of the sphere producing the diurnal motion in each planet was the same as that of the sphere of the fixed stars, and therefore no counteraction to that movement might be thought necessary. The number of restituents was supposed equal to twenty-two, and hence, that of the spheres of both kinds, including the sphere of the fixed stars, was fifty-five. The opinions of the ancients concerning the sphere of the fixed stars, or, as it was commonly called, the eighth sphere, so frequently alluded to in their writings, are very imperfectly known; there is no doubt that, originally, it was supposed to be material and that the stars were imagined to be attached to its interior surface; but a more philosophical sentiment is expressed by Geminus[a], who treats the above as a vulgar error, he observes that some stars are much further from us than others, and alleges, as the reason why we are not sensible of the fact, that the eye cannot judge of distances in directions tending from it. In the *Somnium Scipionis*, Cicero, with whom Geminus was probably contemporary, supposes the spectator to be situated in the Via Lactea,

[a] De Apparentiis Cœlestibus.

from whence, he says, may be seen stars which are not visible from the earth; which seems to shew either that the eighth sphere was thought to be ideal, or that, if material, its thickness was considered of immense extent.

In the age of Aristotle was made the first recorded observation of the sun; and, from it, we derive a proof that the Greek astronomy must then have penetrated beyond the Alps. Pytheas, an astronomer of Marseilles, is said by Strabo[a] to have set up in that city a gnomon and, at the noon of the day of the summer-solstice, to have found that the length of the shadow it cast was to the height of the gnomon itself in the proportion of $41\frac{4}{5}$ to 120; and, as the extremity of the shadow of an upright pillar is formed by the rays emanating from the upper limb of the sun, it follows that the observed zenith distance of that part of the sun's disc must have been 19° 12′ 18″; therefore, correcting this observation on account of the refraction of the atmosphere, for the apparent semi-diameter of the sun and, assuming the latitude of Marseilles to be, as is now known, equal to 43° 17′ 43″ north, it can easily be shewn that the obliquity of the ecliptic to the equator must, in those days, have amounted to 23° 49′ 18″, a determination of considerable importance because, by comparison with others subsequently made, the progressive diminution of the inclination of those circles to each other has been proved. Strabo, we must however observe, alleges[b] that Hipparchus, on the authority of Pytheas, considered the length of the shadow to be the same both at Marseilles and Byzantium; but the latitude of this last place is less than that of the former by about $2\frac{1}{4}$ degrees, therefore the observations made at one or both of these places must have been very erroneous; and if it were not that the obliquity of the ecliptic, determined by the length of the shadow at Marseilles, coincides nearly with that deduced from the rate of diminution which results from a comparison of later observations, little stress would be laid upon this determination in support of the fact that the inclination of the circles has changed. Pytheas is said to have made a voyage to the Ultima Thule (Iceland), where he saw the sun touch the northern side of the horizon on the day of the summer-solstice when at the

[a] Geographiæ, Lib. II. [b] Ibid.

lowest point of his diurnal course; a phenomenon which must have been considered as deciding the question of the earth's rotundity, if any doubt at that time existed concerning the fact.

In this age the influence of the moon upon the waters of the ocean appears to have been observed; for Plutarch[a] expressly states that Pytheas of Marseilles imagined the increase of the moon to be accompanied by the rising of the tides, and her wane, by their falling: it is, also, probable that the Greeks were, then, or soon afterwards, aware of the differences produced in the elevation of the waters by the union or contrariety of the actions of the sun and moon, since, according to Strabo[b], Posidonius describes, in the following manner, the diurnal, the monthly and the annual tides. Speaking of the first, he says, the ocean continues to rise from the time the moon is one sign above the eastern side of the horizon till that of her arrival on the meridian, and to descend from this time till she is near the western side, in like manner, it again rises till the moon is on the meridian below the pole and, subsequently, falls till she has returned to the east. Of the second, he observes that the tides are said to be extraordinarily high at the time of new and full moon, that is, at her conjunction and opposition with the sun, and extraordinarily low when the luminaries are in quadrature; such are, in fact, those we call spring and neap tides. With respect to the third kind, he says, it is found that the tides are the highest when the new and full moons occur at the times of the equinoxes, and similar descriptions of the tides are given by Seneca and Pliny. In earlier times the wildest notions seem to have been entertained concerning these phenomena. Pomponius Mela[c] says it was the opinion of some Pythagoreans that the earth was a living animal, and that the flowing and ebbing of the sea were caused by the emission and inspiration of its breath, but it is easy to perceive that this could have been nothing more than a figure of speech. Plato, in his dialogue Timæus, makes the tides depend upon the greater or smaller quantity of water which flows, from the mountains of Gaul, into the Atlantic ocean: and Seleucus ascribes them to a contrariety in the directions of the movements of the earth and moon, by which the air, being compressed be-

[a] De Placitis, Lib. III. cap. 17. [b] Geograph. Lib. III. [c] Geograph.

tween them, falls on the Atlantic and agitates it with a reciprocating motion [a]. A similar action on the waters is supposed by Aristotle who, however, refers the cause to the sun which, he observes, moves the atmosphere and carries it about the earth; thereby causing the ocean, alternately, to advance, and recede from, the shores.

[a] Plutarch, ubi suprà.

CHAPTER X.

ASTRONOMICAL WORKS OF THE EARLIEST GREEK OBSERVERS.

Formation of the Alexandrian school.—The geometrical and astronomical works of Euclid.—The works of Autolycus—of Aratus.—Observations made by Aristyllus and Timocharis.—The obliquity of the ecliptic and the magnitude of the earth determined by Eratosthenes.—His opinion concerning the motion of the earth.—Method employed by Archimedes for measuring the sun's visible diameter.—Method of finding the parallaxes of the sun and moon.—The systems of eccentric orbits, and of concentric orbits with epicycles.—The various motions of a planet in a simple eccentric orbit explained.—The motion in an epicycle explained.—Nature of the planetary revolutions in the system of epicycles.

WE hear nothing of the Grecian schools after the time of Aristotle, and those Europeans who sought to acquire a knowledge of the sciences, particularly of astronomy, again repaired, for that purpose, to Egypt. The Academia and the Stoa were, probably, still frequented by the youth of Athens to hear the lectures of those who filled the chairs of Plato and Zeno, but the successors of these philosophers seem not to have deviated from the path they had formed, nor to have added to their discoveries any thing worthy of preservation. The decay of science in Greece was, probably, caused by the unsettled state of that country after the death of Alexander; and its revival in Egypt is to be ascribed to the patronage accorded to learned men by the sovereigns who were seated on the throne of the Pharaohs. After the conquest of Egypt, Alexander employed the abilities of Dinocrates in a work more useful than that of cutting Mount Athos into the figure of a man, which the artist had proposed to execute, for he appointed him to superintend the building, near one of the mouths of the Nile, of a city which was to be called by his name, and was, afterwards, to become so famous in the history of the sciences. Here the second Ptolemy, who ruled the African portion of his conquests, established a school which, from the talents of the persons connected with it, was honoured with the epithet Divine. and among these philosophers were some who are distinguished by being the first to

adopt the true method of proceeding in the investigation of the laws of nature, which is that of reasoning not from assumed hypotheses, but from actual observation of the phenomena she presents.

The celebrated Euclid, who lived about three hundred years before Christ, is the first teacher in the institution at Alexandria, whose works have reached us, and we see from his geometrical elements how much greater was the attention then paid to matters of pure speculation than to those of a physical nature. In that work are contained the principal properties of lines and numbers, and of geometrical figures both plane and solid, the equalities of the surfaces and solidities of these last, under various conditions, are proved; and the proportions existing between them are exhibited in cases where comparisons are admissible. In every proposition the most minute care is taken to preserve the rigour of mathematical demonstration; no proof, from a mechanical comparison of magnitudes is made except in a few cases where, from the simplicity of the subject, a different kind becomes inapplicable, and scarcely on any occasion is a thing required to be done, the means of doing which have not been previously given. This great work, which has since been universally employed in elementary instruction, is divided into sixteen books, (the two last of which, however, are ascribed to Hypsicles, another professor belonging to the same establishment,) and contains many discoveries of Pythagoras, Eudoxus, and other celebrated men among the European Greeks: but it is remarkable that though vast labour must have been bestowed in the investigation of these propositions, some of which are of considerable intricacy, no example occurs, in the work, of the application of numeral values to the lines or angles which constitute the figures. It may easily, therefore, be conceived that the values of arcs of circles in the celestial sphere were not, in Euclid's time, expressed by numbers, and that the determination of the sides or angles of figures by any process like that of trigonometry had never, then, been made.

In a treatise on optics, Euclid shows how to measure the height of an object by its shadow, or by viewing its image reflected from a mirror, but no relation is stated between the

angles and sides of the triangle formed by the object, the horizontal plane and the visual ray, and the result is obtained by a simple graphical solution. In the same work we have an example of total ignorance concerning an important point of natural philosophy; when, in speaking of vision, it is said to be obtained by rays of light diverging from the eye in right lines tending to the object; the contrary of which is now so well known. It is worth while to remark that Euclid here describes the forms which cylinders and spheres assume when seen by the eye, because this may be considered as the first circumstance we are acquainted with concerning the history of perspective, to which art, however, it does not appear that the ancients ever paid much attention.

But we are most immediately interested in a work of Euclid entitled *Phænomena*, which relates to astronomy, and, as its name implies, treats of the visible movements of the heavenly bodies: it exhibits some of the first steps made in a new science by one who reasons upon what he sees, without going beyond the first notions arising from a view of the heavens; and, therefore, it may be considered as a proof that astronomy had not, before that time, been reduced to an elementary form. He observes that all the fixed stars describe circular movements about an axis which is oblique to the horizon, and that there is a certain star between Ursa Major and Ursa Minor towards which the axis is directed, a circumstance not strictly correct, since the star alluded to, probably α Draconis, was then at the distance of about nine degrees from the north pole; but it is likely enough that Euclid, in this statement, did not attempt any great precision. The same star is referred to, in a work ascribed to Eratosthenes, and designated the star about which the heavens revolve. For reasons similar to those which we have before given, he concludes that the apparent movements of the stars are conformable to those of bodies on a spherical surface, and he expresses himself as if he considered the stars to be attached to the interior surface of a material shell having that figure. Like Thales he mentions the meridian, the equator, the two tropics, and that which was then called the arctic circle, which was a circle parallel to the equator and touching the horizon on the northern side, consequently

it cut from the sphere a segment containing all those stars which, to the view of the observer at any given place, never set. With these few elements Euclid forms a number of propositions relating to the times at which certain given arcs of the circles of the sphere begin to rise and set, and to those which they employ in ascending above, or descending below the horizon.

About the time of this distinguished mathematician, two astronomical works similar to that just mentioned, and, like it, indicating the very infancy of the science, were composed by Autolycus, a disciple of the same school. One of these works contains the definitions of parallel, right and oblique spheres, and exhibits a few of the properties arising out of the revolution of a sphere, with a uniform motion, about an axis, these are reduced to propositions which are geometrically demonstrated; and, to give an idea of the nature of the work, among many other theorems equally simple, the writer proves that every point on the revolving sphere describes arcs proportional to the times; that, of two points which ascend at the same instant above the plane of any oblique circle, like the horizon, that which is nearest to the pole, in descending, arrives the latest at that plane, and the converse No mention is made of any observation; and it is evident that all such propositions may be illustrated by means of an artificial globe on which the circles of the sphere are represented. The other work treats of the risings and settings of stars, a subject which must, in those days, have been of considerable importance, and which, indeed, during a long period, constituted nearly the whole of astronomy; by these phenomena, the places and movements of the sun were determined and the labours of agriculture regulated, for which purposes, the days when the principal stars would begin and cease to be heliacally visible were ascertained and marked in the calendars. The observations of celestial bodies, when in the horizon, have, however, been long since superseded by those on the meridian, and the times of the cosmical, heliacal, and acronical risings and settings of stars are now contemplated only as far as they may be necessary to illustrate the writings of the ancient astronomers and poets.

The natural way of determining the time when any given star

began or ceased to be visible would be, to suppose the sun at that moment at a certain distance below the horizon, in the direction of a vertical circle passing through the luminary; and in general, the ancients actually supposed that distance to vary from 10 to 18 degrees, according to the magnitude of the star; but Autolycus estimates the distance of the sun below the horizon, at the time of the heliacal appearance of the star, by an arc of the ecliptic equal in extent to 15 degrees, a mode which cannot fail to be in many cases erroneous, because, from the different angles which the ecliptic makes with the horizon in different seasons, the sun, at a given distance from the intersection with the horizon, will be variously depressed in the direction of a vertical circle. In the work of which we are now speaking, Autolycus proves that the heliacal risings of stars will happen some days later than their cosmical risings, and their heliacal settings some days earlier than their cosmical settings, all which is sufficiently evident; and he, afterwards, proves that, of those stars which rise and set, any one will continue visible by night about six months; a loose determination which could be of no use but to enable the observer to anticipate within some days the time at which a particular star would first be seen to rise in the evening, and the period during which it may be seen above the horizon. In later times, when trigonometry was applied to astronomy, the determinations of the risings and settings of stars were more precise, and tables were calculated to facilitate the computations, but since the mode of observing has changed, these have been laid aside as useless. The ecliptic or, as Autolycus calls it, the zodiac, must, in his days, have been divided into twelve equal parts, since he gives the name of dodecatemories, or twelfth parts, to the signs on that circle; but this kind of division does not appear to have been, then, generally used.

About the year 270 Before Christ Aratus of Macedonia paraphrased, as we have before observed, the description of the constellations composed by Eudoxus; and though it is impossible to say how much he may have added to the original work, it probably is but little, since the paraphrase shews only the positions of the constellations and of the principal stars in them relatively to each other, no mention being made of the longitudes

or latitudes, the right ascensions or declinations of the celestial bodies: indeed, of the circles of the sphere themselves, he only mentions the tropics, the equator and the ecliptic or, as he calls it, the oblique circle; and it is remarkable that he speaks of the Galaxy as if it were one of these The constellation Libra is not mentioned, and the claws of Scorpio are described as extending far towards Virgo. He gives to the Pleiades the names of the seven daughters of Atlas, observing that seven were formerly reckoned, though, in his time, there were but six; but he adds that the seventh is not lost, probably meaning that it had only ceased to be visible or was become very obscure; the disappearance of one of these stars is also remarked in a work ascribed to Eratosthenes who, with several other celebrated mathematicians, was contemporary with Aratus. There is reason to believe that in these times, if not in that of Eudoxus, representations of the heavens on a plane surface must have been in use; for, in the description of some of the northern constellations, a misplacement occurs which Attalus, one of the commentators on the work of Aratus, conceives to arise from the circumstance that the figures are drawn as if they were seen from a point on the exterior of the sphere; and Hipparchus, in his remarks upon this passage, asserting the mistake, observes that the figures are drawn just as we see them, meaning that they are drawn as if seen by a spectator placed at the centre of the sphere.

Hitherto the works of the Greek astronomers contain but a dry enumeration of the constellations, and a few notions respecting the risings and settings of the stars, but we are now come to a time when the first efforts were made to obtain some knowledge of the distances and magnitudes of the earth and heavenly bodies, and, though the results of these enquiries were very wide of the truth, yet the methods employed in conducting them display considerable ingenuity and serve to shew how, with better instruments, a useful approximation to the elements of the planetary system might have been obtained.

Among the illustrious men who distinguished themselves at this period as observers of the heavens and who, thereby, contributed greatly to the advancement of astronomy, Aristyllus and Timocharis, the immediate successors of Euclid and Autoly-

cus in the School of Alexandria, deserve particularly to be mentioned, though they are only known to us by the relation which Ptolemy has transmitted[a] of their observations for finding the days of the solstices, and the longitudes and declinations of the stars Spica Virginis, Regulus and Castor: the places of these stars are expressed in degrees and fractions and, therefore, they must have been ascertained by means of graduated instruments; which, consequently, were then in use though, probably, but recently introduced in the practice of the science, for the two astronomers are, also, said to have fixed the places of planets by the intersections of lines passing through the neighbouring fixed stars, and to have estimated small distances in the heavens by diameters of the moon; sure proofs that the old and less correct methods of observing were not, in their time, wholly abandoned. We shall hereafter find that the observations of Aristyllus and Timocharis were used by Hipparchus, together with his own, for the purpose of ascertaining the length of the year; and they are supposed to have afforded this great astronomer a guide to the knowledge of the movement of the equinoxes. The graduated instruments above alluded to must have been similar in construction to those employed by Eratosthenes who, in the order of time, closely followed the two philosophers above mentioned, and, in the account given by Ptolemy of the labours of this mathematician, we have the first description of the nature of that kind of instrument and of the mode of its application in making celestial observations.

There appears to have been placed in the centre of a peristyle at Alexandria a large equatorial armilla which was used by Eratosthenes or some of his predecessors for the purpose of finding the latitude of the place of observation, the obliquity of the ecliptic and the times of the equinoxes and solstices. It consisted of one circle of brass, adjusted so as to coincide with the plane of the meridian, and of a concentric circle, parallel to the equator; and it is easy to conceive that by a plummet suspended from the upper part of the instrument, to shew the position of a vertical line, and an alidade directed to a celestial body, when on the meridian, the zenith distance and declination

[a] Almagest, Lib. VII. cap. 1 and 2.

of that body could be found. The method of determining the arrival of the sun at the equinoctial point by the same instrument may be concluded from an expression used by Hipparchus who relates, speaking of an equinox observed in the thirty-second year of the third Calippic period, that twice in the same day the circle at Alexandria appeared enlightened on both sides; the first time, soon after sun-rise, and the second, about the fifth hour or about an hour before noon [a]; it is evident, therefore, that the circle must have been fixed in the plane of the equator and that the time of the arrival of the sun in that plane was ascertained by the simultaneous illumination of the upper and under surfaces, or by the shadow of the anterior part of the ring falling only upon the thickness of the concave circumference at the posterior part, which, of course, indicated that the sun's disc was bisected by the plane of the circle produced. That the effect should have taken place twice in the day may be accounted for by the refraction of the sun's light, in the atmosphere, being greater when the celestial body was near the horizon than when near the meridian, which might cause its centre then to appear in, and even above, the equator when it was in reality below that plane; but, near noon, the diminution of the declination might compensate the diminution of the refraction and then the sun's centre would again appear in the equator. And it is evident that since, in those days, the effect of refraction was unknown, the time of the equinox, thus determined, must have been, on that account, erroneous

Mention is made by Ptolemy of what is called a solsticial armilla which either was placed, or was intended to be placed, in the same situation, for it is uncertain whether it was actually constructed or whether it was only proposed. It seems to have resembled the last mentioned instrument but to have had no circle in the plane of the equator; and, according to Ptolemy's description, it must have been a circle of brass, placed in the plane of the meridian, having on it two small gnomons or sights (probably one at each extremity of a moveable alidade) that, when the shadow of the upper one covered that below, the graduations of the circle might shew the height of the sun's

[a] Ptolemy, Almagest, Lib. III. cap. 2.

centre above the horizon. We have no information concerning the nature of the graduations but, as Ptolemy always expresses his own observations in degrees and sixths, it is probable that each degree was subdivided into six parts or spaces of ten minutes each, and Delambre supposes that when fractions of degrees less than one sixth occur they were estimated by the eye. With this instrument, if it existed, the latitude of Alexandria may have been determined by Eratosthenes, and Ptolemy supposes it to have been considered equal to 30° 58′; our latest observations make it about 31° 13′; the difference is about fifteen minutes which it will be difficult to account for if we suppose the observations to have been made with the circle just mentioned; for this, by giving the altitude of the sun's centre, would have permitted a result to be obtained much nearer the truth: and, hence, Delambre suspects with some reason that the latitude had been determined not by the armilla but by a gnomon, which, since it gives the altitude of the sun's upper limb would, if no correction were made to reduce it to the altitude of the centre, cause the latitude to be too small by about that quantity.

With the determination of the latitude of the place of observation is connected the problem of the obliquity of the ecliptic; and the latter was probably attempted by Eratosthenes at the same time as the former, either by observing the lengths of the shadows cast by a gnomon, at noon, on the days of the summer and winter solstice, or by taking the altitudes of the sun on those days with the solstitial armilla, for the difference of these altitudes is equal to the interval between the tropics; that is, to double the inclination of the ecliptic to the equator. We are ignorant which of these means was employed by Eratosthenes and we only know that the value he obtained for the above-mentioned interval was $\frac{11}{83}$ of the circumference of a circle, or 47° 42′ 25″; hence the obliquity of the ecliptic must have been 23° 51′ 12″; which is nearly the same as Ptolemy found it to be from his own observations; and this astronomer informs us that 23° 51′ 20″ was the measure of the obliquity employed by Hipparchus.

The globular figure of the earth must have been generally recognized and, as is evident from the value assigned to its circum-

ference by Aristotle, efforts must have been very early made to ascertain its magnitude; but these ancient determinations were probably not, in the days of Eratosthenes, considered sufficiently correct to satisfy the demands of science, and this philosopher seems to have been induced, in the hope of obtaining greater precision, to repeat the observations and admeasurements with greater care and with instruments more accurately constructed. In pursuance of this object Eratosthenes observed, as we are informed [a], that, at Syene in Upper Egypt, on the day of the summer-solstice, the sun, at noon, was exactly vertical, so that a well there was enlightened to the bottom, and that, at Alexandria, on the same day at noon, the sun's zenith distance was equal to one fiftieth of the circumference of a circle; that is, to $7° 12'$; which, therefore, is the difference of the latitudes of the two cities, or the value of an arc of the terrestrial meridian between them, supposing the sun's distance from the earth to be so great that its parallax may be disregarded, and the places to lie under the same meridian, the last of which suppositions is, however, not strictly true. But admitting that these places are so situated and that the earth is of a spherical form or, at least, circular in the direction of the meridian, the distance between them being ascertained, the circumference of the earth might be obtained. Now this distance was measured by order of the government and found to be 5000 stadia; and, hence, the said circumference would appear to be equal to fifty times as much, or 250,000 stadia. It is observed, however, that Eratosthenes made the circumference equal to 252,000 stadia; and hence it is probable that the fraction above mentioned was only an approximation to the value of the true difference of latitude. Now La Place thinks it not likely that Eratosthenes would have contented himself with the rude observation of a well, enlightened to the bottom, for so delicate a problem as that of the latitude of a place, and he supposes [b] that this astronomer employed the lengths of the meridional shadows of the gnomon on the days of the solstices both at Syene and Alexandria; then, if the angles subtended by the shadows were measured by an arc graduated

[a] Cleomedes de Mundo, Lib. I. sect. De Terræ Magnitudine.

[b] Exposition du Système du Monde, Liv. V.

in sixths of a degree, or if the observations were made with the solstitial armilla, which was so divided, it is probable that the difference of latitude would, from the observations, be found equal to 7° 10′ which is equal to $\frac{1}{50\ 23}$ of the circumference for which the simple fraction $\frac{1}{50}$ might have been taken, but 50 23 × 5000 gives 251,150, and Eratosthenes may have taken 252,000 stadia for the sake of round numbers. The principle of the method employed by Eratosthenes to ascertain the magnitude of the earth is the same as that which has been adopted in modern times; and the greater accuracy of our results is due, chiefly, to the improvements which have been made in the construction of the instruments used in linear and angular admeasurements.

Subsequently to the time of Eratosthenes, Posidonius attempted the same problem, and, for this purpose, he observed at Rhodes the star Canopus which, in that latitude, only appears for a short time just in the horizon towards the south, while, at Alexandria, its meridional altitude is 7° 30′, or $\frac{1}{48}$ of four right angles; which, therefore, is equal to the difference between the latitudes of the two places; then having found, probably by the time spent in sailing from one to the other, the arc of the earth's surface between them to be equal in length to 5000 stadia; and supposing both to lie on the same meridian, he concludes that the circumference of the earth is 48 × 5000, or 240,000, stadia [a]. Ptolemy, by similar means, makes the circumference equal to 180,000 stadia; and we have shewn that Aristotle supposed it to be 400,000 stadia. The differences between these numbers are too great to allow us to imagine that they are due to errors in the operations and, therefore, it is evident that the stadia in which the measure is expressed could not have been of the same kind; indeed it is well known that, among the ancients, the stadium was of uncertain length, varying at different times and in different places. M. Bailly [b] considers the round numbers in the above expressions as affording a proof that the stadia were certain arbitrary portions of the circumference of the earth, assumed for the sake of forming a standard of measure whose length should have reference to that of an invariable object in

[a] Cleomedes de Mundo, Lib. I. [b] Astron. Mod. Eclairc. Liv. III. sect. 5.

nature; and the opinion is, certainly, not destitute of probability nor is the practice without example in modern times, for it is remarkable that, soon after the death of Bailly, a standard of that kind was adopted in France; the metre, or unit of length, having been fixed at one forty millionth part of the earth's circumference, supposed to be measured in the direction of the meridian.

When the magnitude of the earth had been determined it must have been easy to obtain an approximate knowledge of the moon's distance from it: for, knowing the semidiameter of the earth and the difference of latitude of two places on or near the same meridian, as Alexandria and Syene, or Rhodes and Alexandria; by appointing persons at both places to take simultaneously the zenith distance of the moon when on the meridian, there will be obtained data sufficient to determine by a graphical process, or otherwise, the distance required. It is highly probable that this element was, in or about the time of Eratosthenes, by some such means ascertained; but some doubt seems to have existed about its real value, for Plutarch[a] observes that those who assign the least value to the distance of the moon from the earth make it equal to fifty-six semidiameters of the latter, Ptolemy shews[b] that Hipparchus made the distance from 62 to $72\frac{1}{2}$ semidiameters, but, in his own computations, he supposes it equal to sixty, and this last value is very near the truth.

Aristarchus of Samos, Archimedes of Syracuse, and Eratosthenes of Alexandria lived at or about the same time, and, while the last was employed in ascertaining the magnitude of the earth, the first distinguished himself by the method he proposed for determining its distance from the sun. In his yet extant work *De magnitudinibus et distantiis solis et lunæ* Aristarchus shews that when the moon's disc is dichotomised, or exactly half enlightened, two lines drawn, one from the moon to the earth and the other from the moon to the sun, make with each other a right angle; and he directs that the angular distance of the sun from the moon should at that time be taken, which is possible because both of them may be then seen at once above the horizon, this angle, he states, will be equal to $\frac{29}{30}$ of a right angle; that is, to 87 degrees; and, by a graphical construction

[a] De Facie.

[b] Almagest, Lib. V. cap. 14.

of the problem, he from thence determines that the distance of the sun from the earth is about nineteen times as great as that of the moon from the earth. The idea of Aristarchus is undoubtedly just and does great honour to his sagacity, but two great difficulties must have presented themselves in reducing it to practice, of which one is the uncertainty of the exact time when the moon is dichotomised and the other, the measurement of the angular distance by such instruments as were then in use; for we, now, know that it is less than a right angle by about 8 or 9 minutes of a degree, only, whereas Aristarchus supposed it to be less, by 3 degrees; and consequently the distance of the sun from the earth is above twenty times as great as it is made to be in the above determination. Succeeding philosophers, by employing the same method and more perfect instruments, obtained results much nearer the truth and, according to Pliny, the distances of the moon and sun from the earth were found by Posidonius to be, respectively, two million stadia and five hundred million stadia, but these values, which do not differ considerably from those assigned by modern astronomers, could only have been brought out by some fortunate chance arising from a compensation of errors. It was not till after the middle of the last century that the distance of the sun from the earth was ascertained with any thing like precision and, in the accomplishment of this end, means were employed of which the ancients could have had no idea.

Some confusion prevails in the accounts we have of the value assigned by Aristarchus to the visible magnitude of the moon. In the work above quoted he states, probably from the observed duration of central eclipses of that luminary, that the semidiameter of the earth's shadow in the region of the moon or, as he calls it, the circle separating the light from the shadow, is equal to the diameter of the moon, again, in one place he makes the latter equal to $\frac{1}{180}$ of the circumference of a circle, or two degrees, and in another, the semidiameters of the sun and moon together are made equal to the same quantity; it is probable, however, that neither of these is what is meant, but that he supposed the diameter of the earth's shadow to be two degrees, which yet is erroneous, for we find it equal to about 82

minutes. Archimedes informs us, in his *Arenarius*, that Aristarchus made the visible diameter of the sun equal to $\frac{1}{720}$ of the zodiac, or to half a degree, which is very near the truth, and it must have been evident that the visible diameter of the moon is about the same as that of the sun; nevertheless he considers the linear diameter of the former to be between $\frac{2}{45}$ and $\frac{2}{30}$ of her distance from the earth, which supposes her angular diameter to be between 2° 30′ and 3° 50′: it must, therefore, be admitted that great errors have found their way into the text of this ancient author, but, whatever may be the values which Aristarchus had found for the visible magnitudes of the sun and moon, he expressly asserts their equality and, from thence, justly concludes that their linear diameters will be directly proportional to their distances from the earth, therefore, agreeably to his previous determination of those distances, it will follow that he supposed the sun to be nineteen times as great, in diameter, as the moon. Aristarchus appears, moreover, to have had a correct notion of the vast extent of the universe, for, as is stated in the *Arenarius*, he observes that the movement of the earth does not much affect the apparent places of the stars, and concludes from thence that these are incomparably more remote, than the sun, from the earth. Such are the determinations of this philosopher; the first, probably, that were made concerning the magnitudes and distances of the celestial bodies; and, from the processes employed, we may perceive not only that the direct observations of angular extent were very incorrect but that there existed no method, or such only as was very imperfect, of applying a numeral calculus in the solution of propositions concerning plane triangles.

Archimedes informs us that Aristarchus had composed a work in which he asserted the annual revolution of the earth about the sun; and, from a passage in Plutarch, the same philosopher appears to have been aware of the fact that the revolution of the earth about an axis oblique to the horizon was the cause of the variable lengths of our days and nights. Plutarch, also, alleges that Cleanthus of Samos had endeavoured to explain the phenomena of the universe by supposing the heavens immoveable and the earth to revolve both in the ecliptic and on its axis. It

is remarkable, however, that Plutarch makes Aristarchus say, the Greeks ought to have prosecuted Cleanthus for impiety in displacing the temple of Vesta by giving motion to the earth; yet, according to Archimedes, Aristarchus held the same doctrine: it is, therefore, probable that either Plutarch or Archimedes has mistaken one of these persons for the other, but the circumstances they relate may serve to shew that the opinion of the mobility of the earth had gained some ground among the learned in their times. The former adds that it had been demonstrated by a philosopher named Seleucus; but the demonstration, whatever it may have been, is now lost. Censorinus [a] ascribes to Aristarchus the invention of a cycle or, as it is called, a great year, consisting of 2484 common years; and Bailly [b] endeavours to shew that this is a period in which two successive conjunctions of the sun and moon with a fixed star would appear to take place according to the values assigned, by the Chaldeans, to the revolutions of those celestial bodies, from which he would draw an additional argument in favour of his opinion of the antiquity of the Chaldean observations; but, as we know nothing of those values, and as Censorinus states that Aratus supposed the same cycle to consist of 5552 years, and Herodotus, of 10,800 years, it must be evident that his hypothesis concerning the cycle of Aristarchus rests on no satisfactory foundation.

Archimedes is said to have been born in the year 287 Before Christ and, like almost every other Greek who devoted himself to philosophical pursuits, to have completed his course of education in Egypt. Besides his investigations and discoveries in pure geometry and mechanics he appears to have paid considerable attention to astronomy, having, as Ptolemy informs us, employed himself in determining the length of the year by reducing and comparing such observations of the solstices as had been made previously to his own time. He is also said, by the poet Claudian, to have invented machinery for representing the motions of the sun, moon, and stars; but we have had occasion to notice, in the dialogue Timæus, what appears to have been an allusion to planetary machines, it is probable, therefore, that the Syracusan philosopher, in this respect, only

[a] De Die Natali, Lib. I. cap 15.

[b] Astron. Mod. Tom. I

improved on the inventions of men who lived in more ancient times: yet the fame he acquired by this piece of mechanism must have been considerable; for Cicero, censuring those who ascribe the formation of the universe to chance or necessity, observes; "*et Archimedem arbitrantur plus valuisse in imitandis sphæræ conversionibus, quam naturam in efficiendis, præsertim cum multis partibus sint illa perfecta, quam hæc simulata, solertius*" [a] In the preceding chapter he alludes to the construction of a planetary machine by Posidonius; and, arguing in favour of the opinion that the universe is the work of Divine Intelligence, he says "*Quod si in Scythiam, aut in Britanniam, sphæram aliquis tulerit hanc, quam nuper familiaris noster efficit Posidonius, cujus singulæ conversiones idem efficiunt in sole, et in luna, et in quinque stellis errantibus, quod efficitur in cœlo singulis diebus et noctibus quis in illa barbarie dubitet, quin ea sphæra sit perfecta ratione?*" From these circumstances, and from the frequent allusions, in the writings of the ancients, to the spheres of Atlas, Anaximander, Eudoxus and others, we can hardly doubt that such machines were frequently made, and it is probable that every philosopher of reputation found it necessary to have them for public exhibition or, at least, for the purpose of aiding the instructions he delivered to his disciples.

The Arenarius mentioned above is a curious work, addressed by Archimedes to Gelo, the son of King Hiero, in which he attempts to prove that it is not impossible to find numbers capable of expressing how many grains of sand would be required to fill a space equal, in extent, to the universe, or to the sphere of the fixed stars, a remarkable instance of learned trifling, and only interesting to us as it gives some insight into the state of astronomy at that time In the course of his inquiry he observes that Aristarchus considered the magnitude of the sphere of the fixed stars to be so great that the circle described by the earth, meaning, perhaps, a sphere equal in diameter to the earth's orbit, is to that sphere in the proportion that the centre of a sphere bears to its surface; or, as Archimedes interprets the passage, as the magnitude of the earth is to a

[a] De Natura Deorum, Lib. II. cap 35.

sphere whose diameter is equal to that of the orbit of the earth or sun. Possibly, however, Aristarchus meant to shew that the sphere of the fixed stars was of indefinite magnitude, but, by this interpretation, Archimedes makes it finite and, from thence, concludes that the particles of sand which would fill it are capable of numerical expression.

In order to find the spherical capacity of the sun's orbit, Archimedes supposes the measure of its circumference to be between six hundred and eight hundred times the diameter of the sun; he, also, assumes the diameter of the sun to be thirty times as great as that of the earth; and this being known from the measurement of Eratosthenes, he has data sufficient for determining that capacity We know not in what manner he found the ratio of the linear diameters of the earth and sun, but the means he employed to measure the angular diameter of the latter deserve to be mentioned. He placed his eye at one extremity of a long alidade, or ruler, which he directed to the sun at the time of his rising or setting, when the light could be supported without inconvenience, and moved upon the ruler, between the eye and the sun, a small cylinder standing on its base, till it just covered the solar disc; then drawing tangents to the opposite sides of the cylinder from the place of the eye, the angle contained between these tangents gave the required diameter: he measured the circular arc subtending this angle, probably by means of its chord, on the circumference of a circle having an equal radius, and found it to be between $\frac{1}{164}$ and $\frac{1}{200}$ of a quadrant, that is, between 32′ 56″ and 27′; the mean of which is 29′ 58″, a quantity rather too small since we know that the mean angular diameter is equal to about thirty-two minutes, but it is impossible that such a method should afford a nearer approach to the truth. The most remarkable circumstance in this account is, that the angle at the eye should, by so great a mathematician, have been determined by a mechanical process instead of a trigonometrical operation, which would have been much more accurate; and it affords another proof that the numerical solutions of plane triangles had not then been discovered.

We find soon after this time that the parallaxes of the moon and sun entered into astronomical investigations as quantities

approximatively known; and, since we have no account of the steps first taken in the research of these elements, it will be proper to shew how from the data then possessed they might have been discovered. It must be observed, however, that the value obtained in the manner we purpose to describe would, from the inaccuracy of the data, necessarily differ widely from the truth; and those employed by Hipparchus and Ptolemy, in fact, did so differ; yet they were not without their use, and, in proportion as the instruments of observation were improved, the parallaxes, at least that of the moon, by whatever means determined, gradually became more correct.

Let S V [Plate I. fig. 3] be an indefinite line joining the centres of the sun, earth and moon when in conjunction, or at the time of a central eclipse of the sun or moon; assume E M or E M′ of any length at pleasure to represent the distance of the moon M or M′ from the earth E, and, since Aristarchus found the distance of the sun from the earth to be nineteen times the distance of the moon from thence, we may make E S equal to nineteen times E M; then S may represent the centre of the sun: now, because the visible magnitudes of the sun and moon were supposed, by Archimedes, to be equal, each, to about thirty minutes, by drawing E a, E b to make an angle of 15′ on each side of E S, we shall have a b for the linear diameter of the sun, and c d for that of the moon: again, in central lunar eclipses, the semi-diameter of the earth's shadow in the region of the moon was found by Aristarchus to be equal to the diameter of the moon; therefore, if we make M′ f and M′ g respectively equal to c d, the lines a f, b g will determine the cone of shadow cast by the earth; consequently h k is known, and the angle at V. Lastly, by drawing M′ k and S k, the angles E M′ k and E S k, which are, respectively, the parallaxes of the moon and sun, are found All the linear dimensions here supposed to be computed will be expressed in terms of E M, but the diameter h k of the earth being supposed to be known, it is evident that, by proportion, the values of those dimensions may be found in stadia or any other measures of length.

We have no account, in any writings which have been transmitted to us by the ancients, of the observations made before the

time of Hipparchus on the movements of the planets; and it is probable enough that such observations, from which the most useful information concerning the system of the universe might have been drawn, were too much neglected by the Greeks, who seem to have had but little taste for the method of philosophising by interrogating nature: but that the situations and movements of the planets had been in some measure attended to, perhaps as early as the time of Eudoxus, may be concluded from the hint given in the Timæus about the complexity of the theories of Mars, Jupiter and Saturn; and that many particulars relating to the planetary orbits had been then, or soon afterwards, discovered by observation may be conceived from the circumstance that the hypotheses proposed by Apollonius of Perga are founded upon data which must have been previously obtained in that manner.

This philosopher is supposed to have lived about 242 years before Christ, and Ptolemy relates of him that, pursuing the ideas of Plato concerning the supposed perfection of circular and uniform motions and, wishing to reconcile with these ideas the apparent irregularities observed in the movements of the planets, he invented two different systems, in one of which the planets were supposed to revolve on the circumferences of circles whose centres do not coincide with that of the earth, and in the other, denominated the system of epicycles, each planet was supposed to move on the circumference of one circle while the centre of this circle is carried round the circumference of another which is concentric with the earth, the latter being supposed stationary in the centre of the universe. The invention of these systems constitutes the first deviation from the principles which were, among the ancients, considered as fundamental laws of nature: hitherto all the circles or spheres employed to produce the phenomena of planetary motion were homocentric, now we find this hypothesis abandoned, but how many ages were yet to elapse before the prejudice in favour of circular and uniform motions could be vanquished? Apollonius and his disciples still tenaciously adhered to these ancient opinions and, rather than quit them, suffered themselves to be involved in an intricate combination of movements which very imperfectly

represented the observed phenomena, while the simpler and more correct hypothesis lay almost within their view. It is uncertain whether, originally, the epicycles and their deferents, or the circles on whose circumferences they were supposed to move, were considered as objects of the imagination, or as existing in material spheres; the language of the ancients seems to favour the last opinion, but it is not likely to have ever been seriously entertained by their men of learning. The formation and development of the systems of Apollonius must have required a knowledge of the times when the planets were in their apsides, and of the situations of those points in the heavens; the times when the planets were stationary, and the extents of the arcs both of the direct and retrograde movements: these must have been obtained from observation in order to compute the radius of the eccentric orbit and the position of its centre, or the proportion between the radii of the homocentric circle and the epicycle, and it is impossible to doubt that the deductions of theory were compared with the phenomena actually observed in order to satisfy the mind concerning the justness of the systems; it must, therefore, be admitted that such observations as are here supposed must have been made in, and before the time of Apollonius.

To explain, from the account given by Ptolemy[a], the observed inequalities and the changes in direction of the movements of the planets, according to the hypothesis of a simply eccentric orbit, let E (Plate I. fig 2) be the earth or centre of the universe, A B P D the circular orbit of a planet, and C its centre; draw the line A P through C and E, then E C will be the eccentricity of the orbit, A and P the points of apogeum and perigeum respectively. Now the planet and the circumference of the eccentric orbit are supposed to have uniform and independent movements in contrary directions about E and C respectively; the former from A towards B, which is direct, or according to the order of the zodiacal signs, and the latter, from A towards B′ or in retrograde order; it is therefore evident that when the two movements are equal, as seen from E, the planet will appear stationary, and when the apparent velocity of the

[a] Almagest, Lib. XII.

eccentric is less or greater than that of the planet, the movement of the latter will appear direct or retrograde respectively. Now, to find the eccentricity of the orbit; let D and D′ be the points in which the planet appears stationary; imagine also the lines B E D and B′ E D′ to be drawn and let fall C F′, C F perpendicularly upon them; then if F D′ be multiplied by v, the angular velocity of a point in the eccentric about C, which may be considered as the velocity about F; the product will express the linear space imagined to be described by D′, in a very short time, perpendicularly to F D′. again, if E D′ be multiplied by V, the angular velocity of the planet at D′, about E; the product will also express the linear space described by the planet in a very short and equal time, perpendicularly to F D′: but these spaces are described in opposite directions by hypothesis, and, when the planet is stationary, they are equal to one another, or F D′.v = E D′. V, it will, therefore follow that, at the point D′, the lines F D′ and E D′ are to one another as the velocity of the planet in the eccentric is to the velocity of the eccentric; it is also evident that the movement of the planet will appear to be retrograde while it is describing the arc D D′, and direct in every other part of the orbit; and that, at P, the retrograde velocity is the greatest while the direct velocity is the greatest at A. The velocities of the planet and of the eccentric being assumed, we have the ratio of F D′ to E D′; consequently that of F D′ to E F; and supposing F D to be equal to C A, the radius of the eccentric, the value of E F will be known in terms of C A; therefore, if the two places of the planet in the heavens be observed, when it appears stationary, the arc D D′ between them will be known, and consequently its half, which, from the construction of the figure, is evidently equal to the angle D E P or C E F: then in the right angled triangle C E F, there will be data sufficient to find the eccentricity C E. Conversely, if this were known by other means, it is evident that the ratio between the velocities of the planet and eccentric might be found.

This theory of a simple eccentric orbit does not appear to have been long in use; for, except a short notice of it which is found in the works of Hipparchus, no circumstances connected with it have been preserved: the theory of epicycles, which

from a passage in Plato's work *De Republica* (where mention is made of small circles applied to other circles) is supposed by Theon to have been first imagined by that philosopher, has, on the contrary, been considerably developed, because it could be more easily modified to suit the variations, at subsequent times discovered, in the movements of the planets. In fact, while a simple inequality of motion was observed, either of the hypotheses might be indifferently employed to represent it, as is observed by Ptolemy, who demonstrates [a] that the apparent movements will be the same, in both systems, if the radius of the epicycle, in the one, be made equal to the eccentricity in the other, but he adds that, when a planet has two different inequalities, both hypotheses must be combined in order to explain them; and this combination enters into his own system.

To exhibit an outline of the theory of epicycles, let E (Plate I. fig. 5) be the earth, or centre of the homocentric deferent circle X C Y, and C the centre of the epicycle A B D; also, let it be supposed that the movement of the planet on the epicycle is retrograde, that is, according to the order of the letters A B′D′, and that the centre of the epicycle moves in direct order, or from C towards X; then, the velocity of the planet in the epicycle being less than that of epicycle itself, about E, its motion will be slowest at A, or *in apogeo*, and swiftest at P, or *in perigeo*, but, as seen from the earth, the motion, like that of the moon, will be always direct. Again, if the planet move on its epicycle in direct order, or from A to B, and the radii of the epicycle and the deferent be supposed to be such that the ratio of C P to E P is greater than the ratio of the velocity of the epicycle to that of the planet in the epicycle, then, as Apollonius shews [b], two lines B E, B′E may be so drawn that if the perpendiculars C Q, C Q′ be let fall on them from C, the segments Q D and D E, Q′D′ and D′E may be to each other respectively in the same proportion that the two velocities above mentioned bear to each other: and it will be found that, in the points D and D′, the planet would appear stationary when seen from the earth; for the angular velocity of the planet about C being multiplied by Q D will express the linear space which the planet would describe, in

[a] Almagest, Lib. III. Cap. 3. [b] Ptolemy, Almagest, Lib. XII.

a small portion of time, perpendicularly to Q D or Q E, and the angular velocity, about E, of the centre of the epicycle, or of any point D in that circle, being multiplied by E D, will give the linear space which D would describe in an equal portion of time, also perpendicularly to Q E; and these movements being equal and in contrary directions when the planet is stationary, it follows that the above proportion holds good when the planet is in D and, for the same reason, also when in D′: and, because we have supposed the velocity of the planet to be less than that of the epicycle, its movement will appear retrograde between D and D′, and direct in every other part of the circumference of the epicycle. In the hypothesis just described it is evident that the true and apparent places of the revolving body will coincide when the latter is in the two points A and P of its epicycle, which are in a line joining the centres of the epicycle and homocentric; and that when the planet is at H and H′, where lines drawn from the earth, at E, are tangents to the epicycle, its apparent velocity is equal to its mean velocity, since it seems then to move only with the velocity of C, the centre of the epicycle.

In developing the system of epicycles, it appears that, for the inferior planets, Apollonius supposed the centre of the epicycle to coincide always with the mean place of the sun; consequently, that the time of a revolution of this centre about the earth was equal to the length of the solar year, also, that the period of a revolution of the planet in its epicycle or, as it was then called, an anomalistic revolution of the planet, was equal to the interval between two inferior, or two superior conjunctions with the sun, and the situation of the line of the apsides, or line of inferior and superior conjunction, for the inferior planets, was supposed to pass through the earth and the mean place of the sun at the middle of the interval of time between two equal elongations of the planet eastward and westward from that luminary. It is probable that, at first, the situation of this line was determined by the true place of the sun but the results of calculation being, on this hypothesis, found to disagree with the observed phenomena the other hypothesis may have been, subsequently, adopted in order to produce a nearer approach to conformity between the theory and the observations. With respect to the superior

planets, the centre of the epicycle of each was made to move on the circumference of the deferent with the mean geocentric velocity of the planet, and the velocity of the latter on its epicycle was supposed to be equal to the difference between the mean motion of the planet and that of the sun. It does not appear that Apollonius conceived the existence of more than one epicycle for each planet; and it is probable that the compound epicycles were introduced to explain the additional variations discovered in the movements of the planets subsequently to the time of the astronomer of Perga. It is, also, uncertain whether the proportions between the radii of the epicycles and the deferents, for all the planets, were investigated by Apollonius, though this is extremely probable; but these, and several other elements which, according to the system in question, enter into the constitution of the orbits, were determined by Hipparchus and, with his own subsequent investigations, are consigned in the writings of Ptolemy.

CHAPTER XI.

THE DISCOVERIES OF HIPPARCHUS.

Trigonometry introduced by Hipparchus.—His catalogue of stars.—His instruments and manner of observing.—The discovery of the precession of the stars in longitude.—Manner of regulating the length of the day.—The length of the year found by observations.—Correction of the calendar proposed by Hipparchus.—Investigation of the solar orbit.—Lunar periods determined by Hipparchus.—Acceleration of the moon's mean motion.—The nature of the lunar orbit.—Data for the elements of the orbit obtained from ancient eclipses.—Investigation of the lunar orbit on the hypothesis of an epicycle.—Manner of finding the moon's angular diameter.—The parallaxes of the sun and moon.—Nature of the planetary orbits.—Investigation of the periodical times and movements of the planets.—Enumeration of the works of Hipparchus.

By the writings of Hipparchus the science of Astronomy was destined to receive so many valuable improvements that it may be almost said to have taken, from them, a new form. Before the time of this philosopher it consisted of a few general theorems of little value, because there were wanting the means of obtaining, by a numeral calculus, the measures of the times and spaces which are the subjects of investigation; and to him we are indebted, very probably, for the invention and, certainly, for the first application of trigonometry in these researches, by which the facility of fixing with precision the places of the celestial bodies and of exhibiting the variations of their movements was, in an important degree, augmented.

Hipparchus first distinguished himself by the commentary on the poem of Aratus before mentioned, and in this is contained the earliest hint we meet with concerning the employment of geometry in questions relating to practical astronomy; the instance occurs in a problem which is of considerable intricacy, and which must have been of essential utility in the ancient science. He supposes a certain star to be situated in the horizon, its right ascension and declination and, also, the latitude of the place of observation, to be known; he then gives, as the results

of calculation, the diurnal arc described by the star, the longitude, right ascension and declination of the point of the ecliptic which is in the horizon with the star; the right ascension of the midheaven and the culminating point of the ecliptic at the time when the said star is in the horizon. Now these elements might have been determined by inspecting a common artificial globe; by geometrically constructing the circles of the sphere on a plane, or by trigonometrical computation; but the words of Hipparchus plainly shew that one of the last two methods was employed, for he states that he had demonstrated the solution of the problem by *a figure*, in his treatise on the simultaneous risings and settings of stars: unfortunately this work is lost, as well as the twelve books which he had written concerning the calculation of a table of *chord lines* inscribed in a circle; a table which must have been intended, like that of the *sines* of arcs in modern trigonometry, to facilitate the computation of the unknown parts in plane or spherical triangles.

A knowledge of the positions of the fixed stars is the basis upon which the whole of astronomy rests; and one of the greatest benefits which Hipparchus conferred upon the science consists in the formation, from his own observations, of a catalogue said to have contained the places of above one thousand of the principal stars. It is uncertain what was the kind of instrument employed in making these observations; for if, as is supposed, the catalogue given by Ptolemy was formed from that of Hipparchus, it would seem that the situations of the stars were expressed by their longitudes and latitudes; and these might have been obtained, either by direct observation or by getting the right ascensions and declinations in that manner, and determining from those elements the positions of the stars, with respect to the ecliptic, by calculation. But as Hipparchus distinguishes the places of stars, in his commentary on Aratus, by their right ascensions and declinations, it is probable that he pursued the latter method in forming his catalogue, and, in this case, the instrument employed must have been a species of equatorial, in which one of the circles was adjusted to coincide with the plane of the equator; there might be another circle perpendicular to this and capable of turning on the polar axis; and, in the plane

of this last, might be an alidade turning upon the centre of the armillæ and carrying the sights by which the star was to be observed. In naming the right ascension of λ Draconis, he says the star, on its parallel, was in three degrees of Leo, meaning, as Delambre observes, that its right ascension was equal to about $4^s\ 3°$, or 123 degrees, and the last-mentioned astronomer thinks it probable, from the above expression, that the right ascension was measured with such an instrument, on the star's parallel of declination [a]; but this does not necessarily follow, and it is more likely that the right ascension was measured on the equator of the instrument between its equinoctial point and the horary circle passing through the star at the time of observation: be that as it may, it is certain that Hipparchus supposed the equator as well as the ecliptic to be divided into signs, or spaces of 30 degrees each; and if we compute from the present tables, making the necessary allowance for the movement of the equinoctial points since the time of Hipparchus, it will appear that the right ascension of λ Draconis was then equal to 121° 42′; the error, consequently, is about 78 minutes, which will not appear surprising when we consider the probable imperfection of the instrument and the manner of making the observation.

Ptolemy quotes an observation of the moon made by Hipparchus at Rhodes, in the year 197 from the death of Alexander, with an astrolabe which was capable of being adjusted to coincide with the plane of the ecliptic in the heavens, and by which consequently, the longitudes and latitudes of celestial bodies and the places of the nodes of the moon or any planet, might be directly obtained: but the difficulty of verifying the position of the instrument must have rendered the use of it inconvenient, and the observations made with it liable to many inaccuracies; it is probable, therefore, that it was not so generally employed as the equatorial astrolabe before mentioned, for the adjustment of which it was only necessary to find a horizontal plane, to trace on it a meridian line and to give to the plane of the principal circle an inclination to the former plane invariably equal to the complement of the latitude of the place of observation

From the ancient accounts of the situations of fixed stars and

[a] Histoire de l'Astronomie, tom. I.

planets, with respect to the equinox, we find that it was the practice to obtain the distances of these from the sun in longitude or right ascension by the intervention of the moon. On account of the impossibility of seeing the sun and star at the same time by the naked eye, the distance of the latter from the moon, when both were above the horizon, was observed by some instrument; then, by means of the known synodical movement of the moon, her distance from the sun was found and, consequently, that of the star from the sun; but the place of the sun with respect to the equinoctial points being also known, that of the star from the same points was determined We have here supposed the moon's distance from the star to be measured, but it is evident that a conjunction which could be observed by the unassisted eye, or an appulse in which the distance could be estimated, may have been occasionally employed and, in fact, such was the more ancient manner of ascertaining the places of the stars. But in whatever way the distance of a star from the moon was found, it is obvious that its longitude or right ascension must have been affected by the errors then existing in the values of the lunar movements, and this evil could not be removed till the invention of telescopes, which permitting some of the principal stars to be seen in the day-time, it became possible to dispense with the moon and to determine the difference in the right ascensions of the sun and star by direct observation. It may be observed in this place that Hipparchus, probably, was not, at the time of writing the commentary, acquainted with the movement of the equinoctial points in the heavens; for he seems to suppose that the places of the stars, in the time of Eudoxus, were the same as those he assigns to them from his own observations, which were made above two hundred years later; and it is from this circumstance that the commentary on Aratus has been supposed to be one of his earliest works A remark made by Ptolemy [a] proves that Hipparchus, after determining the places of the stars, had made a representation of the heavens on the surface of an artificial globe, which appears to have been deposited at Alexandria.

The principal circumstance from which an argument can be

[a] Almagest. Lib. VII. Cap. 1.

drawn in favour of the opinion, that this celebrated philosopher subsequently became acquainted with the fact of the precession of the stars, or rather the retrogradation of the equinoctial points, is the comparison he made of the place of the star *Spica Virginis*, determined by himself, with that assigned to it by Aristyllus and Timocharis about 170 years previously. He states that, in his time, this star was distant 6 degrees from the autumnal equinox, or that its longitude was 174 degrees; a fact which Ptolemy supposes he had ascertained by an eclipse of the moon observed in the thirty-second year of the third Calippic period, when the star was in its vicinity, but the astronomers above mentioned had found, probably in a similar manner, that the same star was 8 degrees from the equinox: now, if Hipparchus felt any confidence in his own observations and in those of Timocharis, he could not avoid considering this difference as caused either by a movement of the star in longitude, during the interval, or by a contrary movement of the equinoctial point in the heavens; and, by proportion, he must have found that the one or the other was equal to 42 seconds yearly: it is right, however, to observe that, according to Ptolemy [a], Hipparchus received from the ancients scarcely any other observations on the fixed stars than those which had been made by the two astronomers above mentioned; and, even of these, he adds, the accounts were obscurely delivered: whence it may be inferred that little dependence could have been placed on the value of an element determined by such data. The other argument from which it may be concluded that Hipparchus was acquainted with the retrogradation of the equinoctial points, is drawn from the fact that Ptolemy quotes a work under that title which, he says, was ascribed to him; and, though this circumstance does not, exactly, prove that the former astronomer had written the work, it seems not likely that any person should have attributed to another the composition of a scientific treatise, the honour of which belonged to himself; or that, within the two hundred and fifty years which elapsed between the times of Hipparchus and Ptolemy, the real discoverer of this important element should have been forgotten. Ptolemy asserts, on the authority of the same work, that Hip-

[a] Ubi suprà.

parchus, when he first discovered the precession, thought it took place only in the zodiacal stars, as if the zone containing them had a motion in longitude independent of the movement of the other stars; but, considering, afterwards, that all the stars preserve their relative positions unchanged, he concluded it to be general: and it is added, that he endeavoured to account for it by supposing that, besides the diurnal revolution, the system of spheres appertaining to the fixed stars was affected by a motion about the pole of the ecliptic, in direct order.

The value of the precession, supposed to have been obtained as above stated, must not be considered as near the truth; but a more correct value has since been found by comparing the place of a certain star, in the days of Hipparchus, with that assigned to it in later times. Now Hipparchus, speaking of the star η in Canis Major, says it was in that part of the solstitial colure which contained the summer solstice, meaning that its longitude and right-ascension were then considered equal to 3 signs, or 90 degrees, and, in the year 1750, the longitude of the same star was $3^s\ 26°\ 4'\ 10''$: hence, supposing the observation of Hipparchus to have been made about 130 years before Christ; that is, 1880 years previously to the other, the precession in longitude would be $49''.92$, or nearly $50''$ annually; and almost the same result has been obtained by Delambre, on comparing the longitudes of several stars in the catalogue of Hipparchus with those of the same stars determined by modern observations. It is remarkable that Ptolemy, who must have used a like process, comparing the places assigned by Hipparchus with those found by himself, makes the annual precession equal to $36''$ only, which seems to prove that the observations of Ptolemy were less accurate than those of the more ancient astronomer.

The method of designating the places of stars by their longitudes and latitudes might, as Delambre observes [a], have been adopted by Hipparchus subsequently to the discovery of the precession, on account of the facility it affords in correcting those places, since, the latitudes being but little affected by this motion, the variations are only equal to the precession in longitude in the interval between two given times. The same astronomer

[a] Astronomie Ancienne, tom. II.

also supposes that Hipparchus introduced the practice of reckoning the longitudes and right ascensions from the intersection of the ecliptic and equator in the heavens, for the sake of its convenience in trigonometrical calculations; that intersection, he observes, being a common angular point for all the triangles by which the reductions are made from the plane of one of these circles to that of the other.

The length of the solar day, or the interval between two successive arrivals of the sun at the meridian of any place, was by Hipparchus, from his observations of the daily movements of the sun, found to be variable in different seasons; and in order to reduce this to its mean value he is said to have applied a correction similar to that which has since been called the equation of time. Now, if the day be made to commence with the arrival of the sun at the meridian, it would be easy to shew that this equation must depend on the inequalities in the sun's motion and on the obliquity of his path in the heavens to the axis of the diurnal revolution, which terms being quite independent of the situation of the place of observation, the daily values of the equation, when found and arranged in a table, might be applied immediately to the transformation of apparent into mean time, or the converse, in any climate of the earth: but, while the day was supposed to commence with the rising of the sun, there must have been another cause of inequality in the lengths of days, depending upon the variable inclination of the sun's path to the horizon, consequently depending upon the latitude of the place of observation; and the equation of time, for the same day, must have been different in places not having the same latitude, the simplification of this element was, in all probability, the reason why Hipparchus changed the regulation of the length of the day from the interval between two successive risings of the sun to that between two successive arrivals of the sun on the plane of the meridian; it must be remarked, however, that this philosopher made the day commence at midnight, whereas astronomers now, universally, begin the day at noon, but the other method is still followed in our reckoning of time for civil purposes. The maximum value of the equation of time is said to have been, by Hipparchus, determined to be equal to 33′ 20″, a quantity greater

than the true value, which is known to be equal to about 23 minutes only. It is also worthy of observation, that in or before the time of Hipparchus the hour of the night at which any phenomenon occurred was determined, as we are informed by Ptolemy, by observing what star was on the meridian at the time; for the right ascension of the sun being known, the difference between this and the right ascension of the star is the time required. The star η in Canis Major seems to have occasionally served, by its arrival at the meridian, to indicate the zero for reckoning the hours; its right ascension, which was then exactly 90 degrees, rendering it convenient for the purpose; and, when any other star was observed on the meridian, the difference in time, between the right-ascensions of such star and of that above mentioned, expressed the hour of the night.

The investigation of the laws by which the movements of the sun, moon and planets are regulated is an essential part of the labours of an astronomer; and as soon as the places of the principal fixed stars had been determined with precision, it seems that Hipparchus applied himself to this difficult task, in the prosecution of which he has displayed the resources of a highly expanded mind; and, by the importance of the results he obtained, he has acquired for himself the reputation of being the most successful cultivator of the science among the ancients. The length of the tropical year is the first step in the solar theory which it is necessary to obtain with exactness, not only on account of its utility in the regulation of the calendar, but, also, because upon it depend the elements of the apparent orbit of the sun. Till the time of Hipparchus this had been concluded from comparisons of the observations transmitted by the Chaldeans and Egyptians, with those of later dates; but this distinguished astronomer, who is twice designated by Ptolemy a man of great industry and a lover of truth[a], knowing the uncertainty of the more ancient observations, endeavoured to avail himself of such as had been made nearer his own time, which might, consequently, be supposed more accurate. Now the data to be employed for determining the length of the year may consist of the observed days, either of the solstices or of

[a] Almagest, Lib. III. and IX.

the equinoxes, and there existed in that age an observation of a solstice which had been made by Aristarchus or Archimedes at the end of the fiftieth year of the first Calippic period, or in the year 281 Before Christ; this, Hipparchus compared with one made by himself at the end of the forty-third year of the third Calippic period; that is 145 years later, and it appeared that the latter solstice happened twelve hours, or half a day, later than the time determined by calculation on the supposition that the year consisted of $365\frac{1}{4}$ days, but $\frac{0.5}{145} = \cdot 00345$, or nearly $\frac{1}{300}$, therefore that supposition appeared to be in excess about $\frac{1}{300}$ of a day, and Hipparchus concluded that the number of days in the tropical year was equal to $365 + \frac{1}{4} - \frac{1}{300}$, or to $365\cdot 24655$, a value which is greater than the truth by $6' \; 13''$ only, since, according to La Place[a], the length of the tropical year at that time must have been equal to 365 242215 days, or about $4''\cdot 2$ shorter than in the present age.

But the Greek astronomer conscious of the uncertainty attending the observations of the solstices, from the smallness of the variations in the lengths of the shadows cast by the gnomon, an uncertainty which he admits might amount to a quarter of a day in the time of the arrival of the sun at the tropic, seems to have made an effort to employ the method of the equinoxes, by observations made with the equatorial armillæ, which would be susceptible of more precision, but of this kind of observation there seems to have been none made previously to his time, and he was reduced to the necessity of employing such as were made by himself at an interval of only thirty-three years: the length of the year determined by these observations was nearly the same as that found from the solstices, as before-mentioned, but the last interval of time being too small, the coincidence of the results could hardly be considered as a proof that either was correct. On the faith of these determinations, which were the most accurate then obtained, Hipparchus suggested an improvement in the calendar, in order to keep the seasons to the same days of the year: it had before been the practice to intercalate one day at the end of every fourth year, which was done on the supposition that the length of the year was $365\frac{1}{4}$ days, and he

[a] Exposition du Système du Monde.

proposed to leave out one of the intercalated days at the end of every three hundred years which, it was expected, would leave a very trifling error in the times of the returns of the seasons. It is, however, uncertain whether the recommendation of Hipparchus was attended to by persons in power; and, even if it were so, it could only have been adopted in the calendar of the Egyptians, since there is no account of it in the writings of any other people. But it is probable that in Egypt, as well as in Europe, the correction was considered only as the speculation of a private philosopher, for if we suppose it to have succeeded in gaining the confidence of the public, we shall find it difficult to believe that, at the time of the reformation of the Roman calendar by Julius Cæsar, the mathematicians consulted on the occasion would not have used their influence to procure the introduction of an intercalation which, besides being little more complex than that actually adopted, would have possessed the advantage of very superior accuracy.

The Romans, never disposed to pay attention to subjects of a scientific nature, contented themselves with the lunar year instituted by Numa, till its inconvenience as a means of fixing the times of historical events became so sensible as to induce them, at length, to change it for that which is regulated by the motion of the sun: for this purpose Sosigenes of Alexandria proposed to add 10 days to the 355 constituting the lunar year, increasing the former lengths of some of the months by one day each, constantly, but the month of February, by one day in every fourth year only; the fourth year, thus containing 366 days, was called bissextile, and the added day was intended to correct the error arising from the supposed excess of the length of each year above 365 days. This regulation of the calendar was from that time followed within the limits of the Roman empire; and, after sixteen centuries, the inaccuracy in the value of the excess assumed by the mathematicians of Cæsar was, also by a Roman Pontiff, corrected in a new reformation of the calendar, which is now adopted by all civilized nations.

From a difference in the places of Spica Virginis which, according to Ptolemy, Hipparchus had determined by two eclipses of the moon observed in the thirty-second and forty-third years

of the third Calippic period, the last mentioned astronomer seems to have entertained a suspicion that there was an inequality in the length of the solar year; and it is probable that, in order to ascertain this point, he made those comparisons of the times of the equinoxes and solstices which have been mentioned above. By the first of those eclipses, as Ptolemy informs us, the longitude of the star, determined by its distance, at that time, from the moon, was $5^s\ 23°\ 30'$; and by the other, $5^s\ 24°\ 45'$: the difference, which is $1°\ 15'$, is too great to be accounted for by the precession in the interval between the observations, and at a time when the length of the year was unsettled, it is not wonderful that the cause should be ascribed to a variation in the periodical time of the sun's revolution: this variation is assumed by Hipparchus, who, in speaking of the observations by which the length of the year was determined, expresses an opinion[a] that neither he nor Archimedes could have erred so much as a quarter of a day in the computed times of the solstices; but, since this element is well known to be very nearly constant, we cannot avoid concluding with Delambre that the above difference must have been owing to errors in the observed distance of the moon from the star, or, perhaps, to an imperfect knowledge of the effect of parallax in changing her longitude.

Hipparchus is said by Ptolemy to have found from observation, that the interval between the vernal equinox and the summer solstice was equal to 94½ days, and that from the latter to the autumnal equinox there were only 92½ days, hence it must have followed, that the length of the summer half year was 187 days, and that of the winter half year, 178 days. It is easy to conceive that this unequal division of the year, which could not have been unknown before the time of Hipparchus, may have led, originally, to the idea of representing the sun's orbit by a circle, whose centre is not coincident with that of the earth; and there can be little doubt that Apollonius had investigated the elements of the orbit on this hypothesis, though no account of his researches have been transmitted to us: that Hipparchus did so we have the authority of Ptolemy for saying, but we are ignorant of the processes he adopted; yet, as the last mentioned astronomer informs us that his own investigations terminated in

[a] Almagest, Lib. III. Cap. 2.

the same results, and as he does not claim for himself the merit of having invented a new method of proceeding in the enquiry; we may without hesitation consider that the reasonings of Hipparchus were similar to those which he, himself, has exhibited in the Almagest, and of which the following is an outline.

Let the circle A B D′ (Plate I. fig. 4) be the sun's orbit, of which C is the centre, and let E be the place of the earth; then C E will be the eccentricity, and A P the line of the apsides: through E draw B B′, and D D′ at right angles to each other, then B and B′ will be the places of the sun at the summer and winter solstices, D and D′ his places at the vernal and autumnal equinoxes respectively. Since, as above stated, the interval between the vernal equinox and summer solstice is equal to $94\frac{1}{2}$ days, and between the latter and the autumnal equinox is $92\frac{1}{2}$ days, and that the periodical revolution of the sun is accomplished in $365\frac{1}{4}$ days, we have, by proportion, the arc D B, or the angle D C B, equal to 93° 9′, and the arc B D′, or the angle B C D′, equal to 91° 11′; therefore the arc D B D′ = 184° 20′, and half the excess of this arc above 180 degrees, that is 2° 10′, is evidently equal to D d, or to the angle D C d; consequently C a, which is equal to the sine of this angle or, according to the expression of Ptolemy, to half the chord of twice the angle, may be obtained from a table of natural sines or chords, the radius C A being supposed equal to unity. Again, the difference between the arcs D B and D d gives the arc d B, from which taking the quadrant d b, we have 0° 59′ for the value of b B, whose sine is equal to a F, which therefore may be found from a table of sines; then, by the well-known formula of right angled triangles, C E the eccentricity, is equal to $\sqrt{(\text{C a}^2 + \text{E a}^2)}$, which, when C A is unity, is equal to 0.0415; that is $\text{C E} = \frac{\text{C A}}{24}$ nearly; this element is now known, on a different hypothesis, to be equal to 0.0168, when C A, or the mean distance of the sun from the earth, is equal to unity.

Draw M M′ through E, perpendicularly to A P; then ∠ C M E is evidently equal to the greatest difference between the place of the sun in the heavens, if it could be seen from C, and its apparent place as seen from E, that is, the angle C M E is what is now called the greatest equation of the centre, or what the Greeks

called the maximum prostapheresis, or anomaly: now C E is evidently the sine of that angle, C A being the radius, and the above value, which was assigned to it by Hipparchus, corresponds to an angle of 2° 23′; which, however, much exceeds the truth, for it is now made equal to about 1° 55′. In the right angled triangle C a E the rules of trigonometry give the value of ∠ C E a, which will be found equal to 65° 35′ 5″; but D being the position of the vernal equinox, the angle C E a or its equal A E D expresses the longitude of the apogeum, which is therefore found: also the angle C M E being known, as above, and C E M being a right angle, we have the angle M C E, and its supplemental angle M C A, which is equal to 92° 22′ 46″; and the angle D C d together with A C d, or its equal, A E D, being known, their sum gives the angle D C A: hence the periodical time of the revolution of the sun in its orbit being known, and the motion about C being, by hypothesis, uniform, Hipparchus could find, by proportion, the time in which the sun would move from D to A and from A to M; and the time when the sun is at D, that is in the equinox, being given by observation, he could obtain the time when the sun was in apogeo, and that in which the equation of the centre was a maximum. On the hypothesis here stated Hipparchus computed tables of the solar movements, which Ptolemy has made use of, but their errors must have been considerable on account, both of the erroneous determination of the prostapheresis and of the supposition that the motion of the sun about C is uniform, which is not the case.

After establishing a theory of the sun, Hipparchus applied himself to the investigation of the movements of the moon; a work of greater difficulty, in the performance of which we find that he availed himself of the ancient registers of eclipses and, no doubt, of many direct observations of the moon's places, which may have been made previously to his time, and which must have afforded several useful approximations to the periods of her movements. Ptolemy, who has given the same account as Geminus of the more ancient lunar cycles, or periods in which the restitutions of her inequalities take place, adds that Hipparchus, by comparing the ancient observations with those of his own time, discovered that the shortest period in which the lunar

eclipses return in the same order, and at equal intervals of time, was 126,007 days 1 hour, within which period there were 4267 lunations; 4573 restitutions of anomaly; 4612 tropical revolutions of the moon, minus $7\frac{1}{2}$ degrees, and that the sun made in the same time 345 revolutions with respect to the fixed stars[a]: from the same authority we learn that Hipparchus had discovered, by a comparison of eclipses in which the moon's anomaly and latitude were the same, that in 5458 months, or 161,178 days, there were 5923 restitutions of latitude. Now, dividing the above numbers of days by the several numbers of revolutions, we obtain the corresponding times in which the different revolutions of the moon were performed, and again, dividing 360 degrees by each of these, we have—

12°.19075 for the moon's mean daily synodical motion,
13°.17646 for her mean daily sidereal motion in longitude,
13°.22935 for her mean daily motion with respect to the nodes, and
13°.06498 for her mean daily motion with respect to the apsides: then, by subtracting the last of these from the daily motion in longitude, we get 0°.11148 for the mean daily progressive motion of the moon's apogeum, and, again, subtracting the daily motion in longitude from that with respect to the node, we obtain 0°.05289 for the mean daily retrogradation of the moon's node Lastly, dividing 360 degrees by each of these last two results, we have 3229.3 days for the period of a revolution of the moon's apogeum, and 6806.6 days for that of a revolution of one of her nodes. The place of her apogeum in the heavens might be found by observing, in the registers of the moon's daily motion, two of her places which differ, in longitude, by 180 degrees and, in time, by half an anomalistic revolution: and the place of a node by observing that of the moon in which her latitude is null.

By comparing these results with those which have been obtained from the most accurate observations made in our own times, it is proved that the moon's mean motion has, since the days of Hipparchus, experienced an acceleration, by which the above values are diminished in different proportions According to La Place[b] the increase of the angular space described daily by the moon, in the present age, with her mean motion,

[a] Almagest, Lib. IV. Cap. 2. [b] Exposition du Système du Monde, Note IV.

beyond the daily angular space described in the time of Hipparchus, when expressed in sexagesimal numbers is, with respect to the sun, 0″.00736452, with respect to the apsides, 0″.026879364, and with respect to the node, 0″.001439856: and the same illustrious astronomer shews that these values agree very nearly with those assigned by the theory of gravitation.

Previously to the time of Ptolemy it appears that the moon, like the sun, was supposed to have but one inequality of movement and, in this case, it is easy to conceive that the theory of the moon must have been similar to that of the sun, before described. In fact, the two systems of Apollonius relating to the orbits of the planets were, indifferently, used to explain the apparent variation of her motion; and, in the application of the first, she was supposed to move on a simple eccentric circle with a velocity equal to her mean motion in longitude, while the eccentric itself was made to revolve in the same direction with a velocity equal to that of her apogeum, in the application of the second system the moon was made to revolve on the circumference of an epicycle whose plane, as well as that of the homocentric deferent circle, was oblique to that of the ecliptic; both movements were imagined to be uniform, and the revolution in the epicycle was performed in the time of an anomalistic revolution, while the centre of the epicycle was carried about the homocentric with a velocity equal to her mean motion in longitude.

As the computation of the elements in a simply eccentric orbit have been already shewn, we may now exhibit the method employed by Ptolemy to determine those of an orbit compounded of a homocentric circle and an epicycle: these elements are the radii of the circles and the equation of the centre; and as the investigation involves only a knowledge of plane trigonometry, and Ptolemy professes to follow the method of Hipparchus, it is probable, as Delambre observes, that the whole process may have been taken from the latter astronomer, the explanation may, therefore, without impropriety be introduced in this place.

In obtaining the data, there are employed the three most ancient eclipses of which any accounts have been transmitted to us, and of which it has been supposed that any particulars were known to the Greeks, since, if Ptolemy or Hipparchus had been

acquainted with any of higher antiquity they would not have failed to make use of them. All these eclipses are lunar and were observed at Babylon in the reign of Mardocempadius, who is supposed to be the Shalmaneser of the Scriptures; the first, which occurred in the 27th year of the era of Nabonasser, or in the year 720 B. C., is said to have been total and to have begun about an hour after the moon was risen in the night between the 29th and 30th day of the month Thoth, when the longitude of the sun is stated to have been 11^s 24° 30′; and it is shewn by Cassini that the time of the middle of the eclipse coincided with the 19th day of March, at 3^h 20′ or 3^h 28′ before midnight, according to the reckoning at Alexandria. The middle of the second eclipse is shewn to have taken place at a time which corresponds to the 8th day of March in the year 719 Before Christ, and at 50′ before midnight, at Alexandria; the extent of the eclipsed part is stated to have been 3 digits on the moon's southern limb, and the sun's longitude to have been 11^s 14° 45′. The third eclipse took place in the same year as the last, on a day corresponding to the first of September, and its middle was at 4^h 20′ before midnight, at Alexandria; the extent of the eclipsed part was 6 digits on the moon's northern limb, and the sun's longitude was 5^s 3° 15′ nearly.

Now the mean motion of the sun and, consequently, the relative motion of the moon in the interval between the first and second eclipse; that is, in 354 1042 days, may be found from the known daily motion of the sun (0°. 986) to be 349° 15′; and between the second and third eclipse, that is, in 176.8417 days, to be 169° 30′. The mean motion of the moon in longitude for the first interval is obtained by multiplying her mean diurnal motion (13° 17646) by 354.1042, the number of days; then, rejecting whole circumferences or dividing by 360 degrees, the remainder will be 345° 51′, which is the distance in mean longitude between the places of the moon at the times of the first two eclipses: in like manner, the distance between the mean places of the moon at the times of the last two eclipses will be found equal to 170° 7′. Again, the mean anomalistic motion of the moon between the times of the first and second eclipse is obtained by multiplying the mean diurnal motion in

anomaly (13°.06498) by 354.1042 days, and the whole circumferences being rejected, the movement required will be 306° 25′; in like manner 150° 25′ will be found to be the mean anomalistic motion between the times of the second and third eclipse.

With these data the elements of the lunar orbit were investigated in the following manner. Let E (Plate II. fig. 1) be the place of the earth, C the centre of the epicycle AMP, or the mean place of the moon at the time of the first eclipse, and assume M to be the true place of the moon at the same time; make the arc MPB=306° 25′, the arc BMD=150° 25′; then the arc MD will be equal to 96° 50′: draw BE, ME and DE; then ∠MEB (=349° 15′−345° 51′, or 3° 24′) will be the difference between the true and mean geocentric motions of the moon, in longitude, in the interval between the first and second eclipse, and ∠BED (=170° 7′−169° 30′, or 0° 37′) the difference between the true and mean geocentric motions in the interval between the second and third eclipse; therefore, also, ∠MED (=2° 47′) is the difference between the true and mean movements in the interval between the first and third eclipse. Therefore, C or A representing the mean place of the moon, in longitude, at the times of all the three eclipses, we have the angles MEC, BEC and DEC for the unknown prostaphereses or equations of the moon's centre at those times respectively.

Draw CB, CM, CD, then, because the arcs BM, MD and BD are the measures of the angles BCM, MCD and BCD, these angles are known, and, assuming the radius of the epicycle to be equal to unity, we may compute, by plane trigonometry, the chords BM, MD, BD; with these and the angles BED, MED, we can also find the lines BE, DE and ME, and the angle EMC; hence, in the isosceles triangle MCG we can find MG and the perpendicular CH, by which means HE becomes known, and, in the triangle CHE, we have data sufficient to find CE; consequently PE becomes known; and, by employing the trigonometrical theorems now generally in use, we have CE=11.501, when CP=1. Again, by the equality of the rectangles AE×EP and BE×EF, we may obtain the value of BF, whence, in the triangle BCF, we shall find the angle BCF to be equal to 151° 5′; and from the triangle BCE, the angle BEC or the equa-

tion of the centre, equal to 0° 59′ 10″, and the angle B C A, which is the supplement of B C E, equal to 12° 24′ 6″; this is the angular distance of the moon from the apogeum of the epicycle, at the time of the second eclipse, and corresponds to the *anomaly* in modern astronomy; and in like manner the equations of the centre and the distance from apogeo at the times of the other two eclipses might have been found If E N be drawn, touching the epicycle in N, we shall have, in the triangle C N E, data sufficient to obtain the angle C E N, the maximum equation of the moon's centre, and this will be found to be 4° 59′ 2″: it has been said, above, that at the time of the second eclipse, the mean longitude of the sun was 11^s 14° 45′, by taking away six signs, we have 5^s 14° 45′ for the mean longitude of the moon; and subtracting from this the prostaphæresis, 0° 59′ 10″, we have 5^s 13° 45′ 50″ for the true longitude of the moon at the same time: again, subtracting from this 12° 24′ 6″, the distance of the moon from apogeo, we have 5^s 1° 21′ 44″ for the longitude of the latter point; thus are obtained the several elements of the lunar orbit, and the values above found agree nearly with those determined by Hipparchus.

The radius of the epicycle may, as we have said, be considered equal to the eccentricity of the moon's orbit, in the other hypothesis, and we have just discovered that its proportion to the mean distance of the moon from the earth is as 1 to 11.501, or as 0 0869 to 1: in the modern astronomy the eccentricity of the moon's orbit is to her mean distance as 0.0625 to 1. The maximum equation of the centre, above determined, is not to be considered as constant, that value, having been computed from the data afforded by an eclipse, holds good only when the moon is in syzygy; in other circumstances the equation will be different, but it is probable that this was not suspected in the days of Hipparchus, and that we are indebted, for the first information of the fact, to Ptolemy who discovered it by investigating the elements of the lunar orbit at the time the moon was in quadrature, as will be hereafter explained.

In continuing his investigation of the moon's orbit according to the method followed by Hipparchus, Ptolemy proceeds to shew how the places of the nodes were found. for which

purpose he compares the second of the Babylonian eclipses above mentioned, which took place in the year 719 Before Christ, with another observed also at Babylon in the year 501 Before Christ; in both of the eclipses the extent of the shadow was three digits, on the moon's southern limb, so that her centre must have been equally elevated above the plane of the ecliptic towards the north; in both eclipses, also, the moon was near the apogeum but, at the first, she was near the ascending, and at the other near the descending node. The interval between the two eclipses was 218 years, 309 days, $23\frac{1}{12}$ hours, or 79879 96 days, in which are included 2935.4446 revolutions of the moon from one node to the same; the excess above 2935 complete revolutions is equal to 160° 4′, and this is the distance in mean longitude between the places of the moon at the times of the two eclipses But the equation of the centre at the time of the first eclipse was $+59'$ and at the second, $+13'$; the difference between these, added to the mean distance, gives 160° 50′ for the true distances between the two places of the moon; and, since she was at equal distances from the opposite nodes, it follows that half the supplement, that is 9° 35′, is the distance of the moon from the node; or the moon's longitude at the time of the first of these eclipses exceeded that of her ascending node by that quantity; hence, the former being known, as we have said, to be 5^s 13° 46′, the longitude of the node must have been 5^s 4° 11′.

The inclination of the moon's orbit to the plane of the ecliptic might have been found as we before mentioned by direct observation, at a time when the moon was at ninety degrees from the place of her node; but Ptolemy, or Hipparchus, appears to have attempted to determine this element by means of partial lunar eclipses; selecting for the purpose such as occurred when the luminary was nearly at her mean distance from the earth, because then, her true horary motions in longitude and latitude are nearly equal to her corresponding mean motions; for, supposing the semidiameter of the moon and that of the earth's shadow, in the region of the moon to be known, the sum of these, after deducting the extent of the obscured portion of the moon, gives her latitude, nearly, at the time of the eclipse; then, the proportion of the horary motion in latitude to that in longitude

gives, by similar triangles, the moon's distance from her node; from which, and the latitude thus found, the angle at the moon being a right angle, the required inclination may be obtained.

It had been attempted, as we have said, to obtain the measure of the angular diameters of the sun and moon, directly, by an instrument; but this appearing not sufficiently delicate to shew the variations of the moon's apparent diameter when in different parts of her orbit, Ptolemy, or Hipparchus, being conscious that such variations existed because of her different distances from the earth, had recourse, for this element also, to the data furnished by the registers of eclipses. For this purpose two eclipses of the moon were selected when she was nearly in apogeo; in one of the eclipses the obscure part was equal to one quarter of a diameter on the southern limb, and, in the other, it was equal to half a diameter on the northern limb; the distances of the moon from the node at the times of the eclipses, and the inclination of her orbit were known; hence the latitudes could be computed, and the difference between them was found equal to 7′ 50″ which was, of course equal to the difference of the magnitudes of the obscure parts, and the latter difference being equal to a quarter of a diameter, we have 4 × (7′ 50″), or 31′ 20″ for the diameter of the moon when in apogeo. In a similar way the diameter was found when she was in perigeo and, also, when at her mean distance from the earth; and, in the latter situation, it was made equal to 33′ 30″. The angle subtended at the earth by the diameter of the cone of shadow in the region of the moon was easily determined by the last of the above-mentioned eclipses; for half the disc of the moon being obscured, her centre must have been on the circumference of the section of the shadow, and, as the centre of this is supposed to be in the plane of the ecliptic, the semidiameter of the shadow was then equal to the latitude of the moon, which, being computed, was found equal to 40′ 40″; this is, therefore, the angle subtended by the half breadth of the shadow when the moon is in apogeo; and in the same manner 41′ 22″ was found to be the angle subtended when the moon was at her mean distance from the earth.

As soon as it was known that the magnitude of the earth

bore a finite relation to its distance from the moon and sun, it must have been perceived that the places of these bodies in the heavens would be different according as the point of sight was supposed to be at the centre, or on the surface of the earth; and if the first was considered as the true place, it would be found necessary to correct the observed place on account of the *parallax*, which was the denomination applied to this cause of error. It is not likely that the parallaxes of the moon and sun should have been unknown even in the days of Aristarchus, but the first information we have received of them is derived from the works of Ptolemy, from which we learn not only that Hipparchus was aware of the nature of this element, but, also, that he was in possession of rules for computing the effects of the lunar parallaxes in longitude and latitude, the former astronomer, however, in his investigations for determining the lunar orbit[a], employs some observations on the moon which had been made by Hipparchus, at Rhodes, and in which the luminary was without parallax in longitude, her apparent place being exactly in the nonagesimal degree; that is, in the plane of a great circle passing through the poles of the horizon and ecliptic, it is probable, therefore, that Hipparchus had purposely chosen the times, when the moon was so situated in order to render his determinations independent of that element of whose just value he might reasonably entertain some doubt.

The distance of the moon from the earth being found, as we have before said, (Chap. X.,) to be equal to about sixty semi-diameters of the latter, and the distance of the sun from the earth, according to the determination of Aristarchus, being about nineteen times the distance of the moon, it might be found, by a graphical construction or otherwise, that the horizontal parallax of the moon is about 57 minutes and that of the sun about 3 minutes, and these are the values which Hipparchus appears to have employed in his calculations; the first does not differ much from the truth, but the other, from the error in the distance of the sun, is about twenty times as great as it ought to be.

The effect of the moon's parallax may have been sensible to

[a] Almagest, Lib. V.

the ancients by a disagreement in the observed and calculated differences of latitude or declination, of the moon and a fixed star; or by observing that the distance of the moon from a certain star, when both were together on the meridian, appeared different if seen from two places not having the same latitude; or, finally, by observing that, from two places so situated, a partial eclipse of the sun, on the northern or southern limb, did not appear to be of equal magnitudes; and Ptolemy says[a] that from observations of this kind, by assuming for the parallax of the sun certain small quantities, Hipparchus attempted to find that of the moon; but this method does not appear likely to have afforded any more correct result than that obtained from the magnitude of the earth and its distance from the moon.

The following examples may serve to shew in what manner the motions of the planets were explained by the theory of a simple epicycle, which we suppose to have been adopted in the time of Hipparchus, though the description is taken from the works of Ptolemy. The time of a planet's opposition to the sun has always been considered as the most eligible for making the observations by which its place is to be ascertained, because the planet, earth and sun being, then, in one line, the longitude of the first differs from that of the last by exactly 180 degrees; and the situation of the sun with respect to the equinoctial points being known by direct observation, or obtained from its mean place by equations which could early boast of considerable accuracy, the corresponding place of the planet became, consequently, known with greater certainty than when in any other part of its orbit. This was an advantage, however, which the superior planets alone afforded; Venus and Mercury never come in opposition to the sun, and when in conjunction with him they are invisible; hence the ancient astronomers were reduced to the necessity of making their observations on these planets at the times of their greatest elongations from the sun, which are less easily determined than the time of the opposition of a superior planet.

Now, from the registers of observed oppositions of the superior planets, Ptolemy, or rather Hipparchus, found that, in

[a] Almagest, Lib. V. cap. 11.

59 0048 tropical years, Saturn had come 57 times to opposition; that is, he had made 57 complete revolutions in his epicycle, or there had been 57 restitutions of anomaly as it was then called; that, in 70.9866 tropical years, Jupiter had come 65 times, and that in 79.0097 tropical years Mars had come 37 times to opposition. Therefore, in order to exhibit these phenomena and deduce from thence the values of the mean movements of the superior planets, agreeably to the description of Ptolemy, let E (Plate II. fig. 2.) be the earth, S s S′ the orbit of the sun, A M P the planet's deferent circle and V T V′ its epicycle. Let it be, at first, supposed that the planet is at V′ in the perigeum of the epicycle at the time of opposition, when the sun is at S′, and that it revolves on that circle in the direction V′ V L; then, between the time of that opposition and the next, the centre of the epicycle will have moved from M, suppose to M′, the planet will move to V′, and the sun will describe one complete revolution together with the arc S′ s′, which is the measure of the angle M E M′; but the interval between two oppositions, and it may be added, of two conjunctions, being considered as one revolution of the planet in its epicycle, it follows that such a revolution, (supposed to be through 360 degrees,) is performed in the time that the sun takes to describe 360 degrees together with the number of degrees in the angle M E M′; and consequently, that the mean motion of the planet in its epicycle with respect to the sun, or, as it is called, the mean relative motion, is equal to the difference between the mean motion of the sun and that of the planet, in longitude. Therefore, that the planet may accomplish any number of entire revolutions in the epicycle, the sun must make as many tropical revolutions about the earth together with as many times the arc S′ s′: now, with respect to the planet Saturn, the period of 59.0018 years, within which time 57 complete revolutions in the epicycle were performed, may be considered as made up of 57 + 2.0018 tropical revolutions of the sun; but 2.0048 revolutions on the circumference of a circle are equal to 731.716 degrees, which are those described by M, the centre of the epicycle, in 59.0018 years: hence the periodical time of a mean revolution of Saturn in his orbit about the earth was, by the

ancients, found to be 29 03 years. To find the mean diurnal motion of Saturn, in his epicycle, divide 20520 degrees (= 57 circles) by 21551.5 days (= 59 0048 years), and the quotient, 0°.95214, will be the movement required, 731.716 degrees divided by 21551.5 days give 0° 033486 for the planet's mean daily motion in longitude; and these two movements are equal to the mean daily motion of the sun about the earth · lastly, dividing 21551.5 days by 57, we have 378.09 days for the time of one mean periodical revolution of Saturn in his epicycle, or the interval between two oppositions. In like manner the periodical times and the mean movements of the other superior planets were found.

In determining the times and movements of the inferior planets Hipparchus considers that, as the centre of the epicycle described by each is always in a line drawn from the earth to the mean place of the sun, the mean movement of the planet in longitude, or the motion of the centre of the epicycle is equal to the mean motion of the sun; that is, to 0° 98563 daily: but, for the movement in the epicycle, he found, as is related by Ptolemy, that the anomalies of Venus were restored five times exactly, in 2919.75 days, and those of Mercury, 145 times in 16802.53 days, that is, the planets returned so many times to their greatest elongations from the sun, on the same side of that luminary, in those periods respectively; and, dividing the periods by the number of restitutions, he obtained 583.95 days and 115.875 days respectively for the periodical revolutions of Venus and Mercury in their epicycles in the interval between two such elongations, or, which was then considered the same thing, the interval between two consecutive inferior, or superior, conjunctions with the sun, then, dividing 360 degrees by the number of days in each of those periodical revolutions, we have, with respect to the sun, the mean daily motions of the planets in their epicycles, which are, for Venus, 0 61649 degrees and, for Mercury, 3.10667 degrees. But the return of an inferior planet two successive times to the point of maximum elongation on the same side, or to the point of like conjunction, is accomplished in a period equal to that of its revolution upon the circumference of the epicycle, together with

the time in which it would describe an arc of that circumference subtending an angle equal to that of the sun's movement in the said period; for let E (Plate II. fig. 2.) be the earth; S″s″, described about E as a centre, be part of the sun's orbit, and A M P be the orbit of the centre of the epicycle V T V′; also, let V′ be the place of the planet at its inferior conjunction; then, while the planet has moved on the circumference of the epicycle in retrograde order from V′ to v′, the point of next inferior conjunction, the point S″ has moved to s″, having described the arc S″s″ simply, if the planet be Mercury, and the arc S″s′ together with a complete circumference, if the planet be Venus; in consequence of which, by drawing the line a M′ b parallel to V M V′, it is evident that V′ must have described one circumference of the epicycle together with the arc b v′, which is the measure of the angle b M′ v′, or of its equal S″ E s″. Now multiplying the number of days in the periodical revolutions above found, which are also the times of describing the arc S′s″, by the daily movement of the sun, we have the value of the angle S″ E s″, or b M′ v′; and to this adding 360 degrees, we obtain the angular movements of the planets, in their epicycles, in the times of those revolutions; consequently, by proportion, we get the mean times of the revolutions through the exact circumferences of the epicycles; which are, for Venus 224.71 days, and for Mercury 87.968 days; and, again, dividing 360 degrees by these times, the results will be 1.6021 degrees and 4.0923 degrees, the mean daily movements in the epicycles; these last are evidently equal to the sum of those above, and of the mean daily movement of the sun; and the periodical times just found agree almost exactly with those assigned to the sidereal revolutions of Venus and Mercury by the modern astronomers. The following table exhibits the periodical times and the mean movements of all the planets according to the theory of Hipparchus, but deduced, probably, by Ptolemy himself; for the latter observes[a] that Hipparchus confined his investigations chiefly to the theories of the sun and moon; not having had so many good observations on the planets left to him by the ancients as he left to those who were to follow him.

[a] Almagest, Lib. IX. cap. 2.

	Mean periodical revolution in longitude, or of the centre of the epicycle.	Mean periodical revolution in the epicycle	Mean daily motion in longitude	Mean daily motion in the epicycle.
Saturn	29·03 years	378 09 days	0°·03349	0° 95214
Jupiter	11·86	398 89	0 ·08312	0 90250
Mars	1·88	779 68	0 ·52424	0 ·46173
Sun	1·		0 ·98563	
Venus	1·	583·95	0 ·98563	0 ·61649
Mercury	1·	115 875	0 98563	3 ·10667

Hipparchus was born at Nicæa, in Bithynia, but both Ptolemy and Theon relate that he made many celestial observations at Rhodes, and it is probable that his principal works were composed at that place. Besides the invention or improvement of trigonometry and the computation of tables for the purpose of facilitating its application in astronomical enquiries, he must have spent many years in making observations: his labours in deducing from them and from those of his predecessors the principal elements of the solar, lunar and, perhaps, of the planetary orbits must also have been immense, and we must add to these important objects the formation of his catalogue of 1080 stars; from all which we shall be justified in concluding that this distinguished philosopher was qualified to rank with the most celebrated of modern Europe He died about the year 125 Before Christ.

Little seems to have been done in astronomy between the times of Hipparchus and Ptolemy; for we can hardly consider that the science gained any thing by the works of Hypsicles, Theodosius, Menelaus and the first Theon, who lived in that interval, since these are, apparently, only compilations intended for elementary instruction, and scarcely contain any subject which admits of application to practice. We proceed, therefore, to give some account of the works of Ptolemy, to whom the science is indebted for many considerable improvements.

CHAPTER XII.

IMPROVEMENTS INTRODUCED BY PTOLEMY.

Instruments invented by Ptolemy.—Sun dials and clepsydra employed for measuring time.—Ptolemy's determination of the precession.—His catalogue of stars.—His arguments for the rotundity and immobility of the earth—The obliquity of the ecliptic—The length of the tropical year.—The planetary orbits represented by eccentric deferents and epicycles.—The solar orbit according to Ptolemy the same as that of Hipparchus.—Formation of a table of the equation of time.—Elements of the lunar orbit at the epoch of Nabonassar.—Discovery of the second inequality of the moon's motion.—Investigation of its value.—The diameters of the homocentric and eccentric circles, and of the epicycle.—The moon's parallax, and distance from the earth.—Ptolemy's lunar theory erroneous.

THE researches of Ptolemy, which are, chiefly, contained in the Megale Syntaxis or, as it was subsequently called, the Almagest, relate to the positions of the fixed stars, the length of the year, and the elements of the orbits of the sun, moon and planets; so that this work constitutes a general treatise on astronomy, and it is the more interesting to us as it remained the text-book of the schools both in the East and in Europe till the great revolution in the science took place by the promulgation of the system of Copernicus.

The instruments of observation used by Ptolemy or his contemporaries appear to have been of three different kinds: he describes one with which he measured, or proposed to measure, the zenith distance of the sun and the obliquity of the ecliptic, and which seems to have differed little from the meridional armillæ of Eratosthenes; it consisted of two rings, one moveable upon the interior circumference of the other, in the same plane, which was that of the meridian; the exterior circle was graduated in degrees with as many subdivisions as each degree would contain and the other carried two small gnomons, at the extremities of a diameter, which served to form the line of sight; the whole instrument was fixed on a pedestal and its verticity was ascertained by a plumb-line suspended from the top. Pto-

lemy, also, describes a quadrant which he says may be made of wood or stone and with a moveable alidade carrying sights, like the meridional armilla it is said to have been intended to measure zenith distances but, probably, its radius was made much larger than that of the last mentioned instrument in order to afford more accurate or more minute subdivisions, and it is evident that these two instruments must have served precisely for the same purposes as our present mural circles and quadrants.

But it seems that neither of these instruments gave the zenith distances of celestial bodies with the degree of correctness which was then thought necessary, and Ptolemy invented another [a] which the second Theon afterwards designated the parallactic rods: this consisted of a pillar placed vertically on a foot, at the upper extremity was a joint on which turned a long alidade carrying the two sights, and these were circular apertures pierced in two plates, probably of metal; one of the apertures was recommended to be very small, and the other, rather larger than the visible diameter of the moon in perigeo, evidently, in order that, the whole disc of the sun or moon being visible within it, the position of the line of collimation might be nearly free from error: the alidade was kept in its position, when directed to the celestial body, by a third rod which, also, turned upon a joint in some part of the vertical rod and was graduated so as to shew the angle between the latter and the alidade, that is, the zenith distance required: as the graduated rod could not have been very extensive, we may consider that this instrument answered, in some measure, the purpose of one of our zenith sectors.

Another important instrument which was used by Ptolemy, and, probably also, by Hipparchus, was an astrolabe for taking the distances in longitude between the sun and moon, or between the moon and a star. It consisted of two rings fixed at right angles to each other, one in the plane of the ecliptic and the other in that of the solstitial colure, to these were added two other rings whose planes turned about the axis of the eclip-

[a] Almagest, Lib V.

tic circle so as to form two moveable circles of celestial longitude, and in the interior of one of these was another circle capable of turning in the same plane as that to which it was applied, this carried two sights diametrically opposite to each other, which being directed to a celestial body, the arc of the exterior circle intercepted between the ecliptic and either of the sights gave, by the graduations on that circle, the latitude of the body. In making an observation for longitude, one of the moveable circles was directed to the sun or moon, having been first fixed to that degree of the ecliptic circle which expressed the known, or previously computed longitude of the luminary, by which means the zero of the graduations on the ecliptic circle was made to correspond with the place of the vernal equinox in the heavens, then the other moveable circle of longitude was directed to the second celestial body, whether the moon, a planet or a fixed star, and the arc of the graduated ecliptic circle between the zero and the moveable circle gave, by inspection, the longitude of this second body. It appears that, on the circumference of the solstitial ring, were fixed pins in two diametrically opposite points, representing the poles of the earth, and that the whole machine revolved about the axis passing through these points, which was placed so as to be parallel to that of the earth. From the nature of the fractions of degrees set down by Ptolemy, in stating some longitudes of the sun and moon taken by this astrolabe, it appears that the ecliptic ring was graduated into thirds and, perhaps, into sixths of degrees, but nothing indicates greater minuteness of subdivision. A dioptra is mentioned by Ptolemy as an instrument used in making observations, but it is probable that it merely signified a tube to render vision more distinct by permitting only those rays of light to enter the eye which come directly from the celestial body, and it may, for this purpose, have been attached to the alidades of some of the armillæ or of the parallactic rods.

There is reason to believe that, in making astronomical observations, the ancients used to contemplate the heavens particularly in the direction of the meridian; since we find in their works allusions made to the practice of descending into the earth, in order that they might have a view of the stars, and this

could only have been obtained when the latter were opposite the entrance of the excavation but there is no position, except that of the meridian, in which observations could be constantly made, and we, therefore, feel justified in concluding that these were really made in that plane. Strabo relates[a] that, in his time, there were shewn, in the prefecture called Litopolitana, near Heliopolis, certain caves which had been used for observing the motions of the celestial bodies, and he remarks that similar caves were in existence near Cnidus in Asia. Such excavations, if sufficiently deep, would permit the planets and principal fixed stars to be seen in the day-time; and, if made in the plane of the meridian, would be well adapted for witnessing their transits over that plane, and, consequently, for ascertaining immediately, with instruments, their right ascensions and declinations. Various methods were adopted by the ancients to diminish the brilliancy of the sun's light when observations were made on that luminary: Aristotle states[b] that mirrors were used in his time, and it is probable that these were polished plates of some dark stone: Ptolemy informs us that vessels of oil or some thick liquor were employed for viewing eclipses of the sun, and Seneca[c] mentions the use of a smoked glass for a like purpose.

The knowledge of the hour at which any phenomenon occurred, or any observation was made, is of the utmost importance in astronomy; and, therefore, it will be proper to add to the above description of the ancient instruments for measuring angles some accounts of the first inventions for ascertaining the divisions of the day and night. We have mentioned in the third chapter, that the gnomon might have been, from the earliest times, employed as a sun-dial, and Vitruvius relates[d] that instruments had been constructed by Eudoxus, Aristarchus and others, for exhibiting the hour of the day; of these, the scaphium, or boat, and the discus, both of which are said to have been invented by Aristarchus, appear to be the most simple; the first, which was in the form of a hemispherical cup, was probably placed so that its rim lay in a horizontal position, and

[a] Geogr. Lib. XVII. [b] Meteorol. Lib I. [c] Nat Quæst. Lib. I.
[d] De Architectura, Lib. IX. cap. 9.

the object which cast the shadow might be a horizontal bar forming a diameter to the instrument and placed in the direction of the meridian; then the concave surface being divided into twelve equal parts, by semicircles having the bar for a common diameter, the shadow of this would, at all seasons of the year, divide the day, between sunrise and sunset, into twelve equal parts, or, as they were then called, temporary hours, which, for civil purposes, seem to have been generally used among the ancients, though attended with this inconvenience that, in different seasons, the hours are of different lengths. The discus may have been an equatorial or horizontal dial in the form of a circular plate, as its name implies.

But Vitruvius informs us[a] that a certain Berosus had invented, or introduced into Greece, a dial, which he describes as a semicircle cut from a square and inclined according to the climate: "*Hemicyclium excavatum ex quadrato, ad enclimaque succisum*"; and it is probable that the dial discovered by Stuart on the south side of the Acropolis at Athens is of this kind. From the account given of it in the second volume of the Antiquities of Athens, it appears to be a block of stone so excavated as to have the appearance of one end of a boat cut asunder transversely; the upper surface of the stone is horizontal, but the front is cut in a plane which probably was intended to be parallel to that of the equator, and this seems to be what is meant by the expression *ad enclima*, in Vitruvius; but, if the measures given by Stuart are correct, its declination from a vertical line is only 36° 37′, which indicates a latitude about 1½ degree southward of Athens: the concave surface of the excavation, which is not, indeed, spherical, but in the form of a portion of an hyperboloid, is divided into twelve equal portions by the hour lines; these diverge from the vertex of the concavity and cut the section of its superficies, made by the inclined face of the stone, in as many equal parts The object which cast the shadow is supposed to have been a horizontal bar coinciding, in position, with the axis of the hyperboloid, in which case, as in the scaphium, by the arrival of the shadow at the different hour lines, the day,

[a] In loc. cit.

between sunrise and sunset would, in all seasons, be divided into twelve equal parts. Upon the concave surface are also drawn two curves in planes parallel to the equator, which Stuart supposes to represent the paths of the shadows cast by the extremity of the bar on the days of the equinoxes and of the winter solstice, the extremity of the excavation, on the front of the instrument, representing the path on the day of the summer solstice.

Dials of this kind seem to have been very generally used by the ancients, Cicero, in a letter to a friend, proposes to send one to his villa, and, in 1746, such a dial was discovered in the ruins at Tivoli which are supposed to be those of his Tusculan seat; several others have been since found in Italy, and, in 1762, one was obtained from the ruins of Pompeii similar to that above described but wanting the tropical curves, or those which represent the paths of the shadow on the days of the equinoxes and solstices; its concavity is not spherical and the hour lines are not equally distant from each other, but Newton, the commentator on Vitruvius, ascertained by trial that the planes in which they lie make equal angles with each other; and, consequently, that the divisions of the day were equal, as well in this dial as in the others. the face of the dial declines from the plane of the prime vertical about 31 degrees, which is the position of the equator near Alexandria in Egypt, and it is possible that it may have been brought from that country to Rome.

The most interesting example of the ancient practical gnomonics is exhibited in the dials on the faces of the Tower of the Winds or, as it is called by Varro, the Tower of the Clock, at Athens, of which a description is given, in the first volume of the Antiquities of that city, by Stuart. This edifice is believed to be at least as old as the time of Alexander, and seems to have been expressly made to contain a clepsydra, or clock for shewing the hours by the flowing of water through an orifice, it is of an octangular form, the faces are opposed to the four cardinal, and the four intermediate points of the horizon, and, on each face are the hour lines proper for a vertical sun-dial having that particular aspect. These may not be of the same antiquity as the tower itself, and the silence of Vitruvius concerning them is

an argument in favour of the opinion that they were executed since his time, but this is not conclusive, and it is observed by Delambre[a] that there is nothing in their construction which may not be referred to the age of Hipparchus. The gnomons of all the dials are wanting, but there remain the holes by which they were attached to the walls. From the measurements given by Stuart, Delambre has, by computation, verified the construction of the five principal dials; he finds that the lines represent the temporary hours, or the equal division of the day from sunrise to sunset, and that they are traced with remarkable correctness; but those on the north-east face are the least so, in which he considers the artist excusable because a small error in the graphical operation would, in a dial so situated, sensibly derange the positions of the hour lines. From the construction of the east dial, the latitude of the place appears to have been assumed to be 37° 30′, but modern observations make that of Athens equal to 37° 58′, and it is probable that great accuracy in this element was not attempted by the artist.

Instruments for measuring time by the motion of the sun must of course have been useless by night, or under a cloudy sky; and it, consequently, then became necessary to obtain the hour by means of a clepsydra: according to Vitruvius[b], this was invented by Ctesibius of Alexandria; and, from his description, it is evident that such machines were, also, made to divide the day between sun-rise and sun-set in twelve equal parts, ingenious contrivances seeming to have been used to enlarge or diminish the aperture in proportion to the decrease or augmentation of the lengths of the natural days But this mode of division, by which the hours of the day or night were made of lengths which varied according to the variations of the seasons was attended with great inconvenience to the practical astronomer, and Ptolemy, or rather Hipparchus, introduced the use of the constant, or as they were called, equatorial hours which divide the period between two arrivals of the sun at the meridian into twenty-four equal parts, and are very nearly of the same length in all seasons; and, though no mention is made of them, there can be no doubt

[a] Histoire de l'Astronomie, Tom. II. page 488. [b] In loc. cit.

that both sun-dials and water-clocks, exhibiting this division of the day, were constructed in their times, in order to avoid the trouble of reducing one of these kinds of hour to the other.

The notices given by Ptolemy concerning the fixed stars are contained in the seventh book of the Syntaxis or Almagest, and the most important among them is that relating to the retrogradation of the equinoctial points, which he determines from a comparison of the longitudes of two of the stars, observed by himself, with those of the stars observed by Hipparchus. He states that in the second year of Antoninus, (137 after Christ) the sun being at the point of setting and the moon visible, he found her longitude by the astrolabe, in the manner above described, to be $2^s\ 5°\ 11'$; half an hour afterwards, the sun being set and the star Regulus becoming visible eastward of the moon, the difference of longitude between them was then found to be $1^s\ 27°\ 15'$; but the increase of the moon's longitude in the half hour being computed at 15 minutes, and the moon's parallax in longitude being found by computation to be equal to 5 minutes by which her longitude was diminished, it follows that the true longitude of the moon at this time must have been $2^s\ 5°\ 21'$, and adding this to the difference in longitude, of the moon and star, above found, we have $4^s\ 2°\ 36'$ for the longitude of Regulus. But Ptolemy states that, in the fiftieth year of the third Calippic period, that is 265 years before the time of his own observation, Hipparchus had found the longitude of the same star to be $3^s\ 29°\ 50'$, consequently, in the interval, the equinoctial points must have retrograded as much as $2°\ 46'$, which is equivalent to $37\frac{1}{2}$ seconds, or as Ptolemy makes it, 36 seconds, annually. Now we have seen that the observations of Hipparchus compared with those of Timocharis give, for the annual retrogradation, a quantity between 42 and 59 seconds; and if the longitude assigned by Hipparchus to this star be compared with that which, according to the Greenwich Catalogue, it had in 1820, that is $4^s\ 27°\ 19'\ 41''$; it will appear that the increase of the star's longitude, in the 1948 years which had elapsed from the date of the observation of Hipparchus, amounts to $27°\ 29'\ 41''$; consequently the annual precession of the star would be $50''.8$; nearly the same value is obtained from the observation made by

Hipparchus on the star η in Canis Major, and both the theory of gravitation and the deductions made from the more accurate observations of modern times coincide in indicating 50″.1 for the mean annual value of the precession.

Ptolemy asserts that he had determined, in the same manner, the longitude of Spica Virginis and had obtained from thence the same value (36 seconds) of the precession, and this erroneous value he employs in all the calculations involving that element. Having fixed the positions of these stars with respect to the equinox by their distances from the sun, as above described, Ptolemy obtained the differences of longitude between these and others, and their latitudes, by direct observations with his astrolabe; thus he formed that catalogue which he has consigned to posterity, and which has been of so much service to astronomers by enabling them to detect the changes which have, since his days, taken place in the positions of the stars called fixed. The epoch he has chosen for his catalogue is the beginning of the reign of Antoninus, which corresponds to the year 135 of the Christian era, and to that he has reduced the longitudes and latitudes which he obtained from his observations. But, on comparing the longitudes he assigns to the stars with those in the catalogue of Hipparchus, it appears that the differences between them are such as would result from merely augmenting the latter by the amount of the precession in the interval of time elapsed between the epochs of the catalogues, at the annual rate of 36 seconds; now this is unfortunately incorrect and the uniformity of the differences has given rise to a suspicion that Ptolemy did not, actually, make any observations on the fixed stars, but merely copied their places from the works of the more ancient astronomer, adding to the longitude of each star the change caused by the retrogradation of the equinoxes in the interval. This suspicion appears to be, however, unfounded, and La Place, on the supposition that the longitudes assigned to the stars by Hipparchus are correct, observes that it will be possible, from the erroneous determination of the length of the year, made both by Hipparchus and Ptolemy, to account for the error of the latter in the value of the precession; for the length of the year being too great by about 6 minutes, the daily motion of the sun

and, consequently, at any given time, his distance from the equinox, according to the tables, would be too small; this would render the longitudes of stars, determined by Ptolemy from observation, also too small, seeing that they were obtained by an instrument adjusted to the computed place of the sun; therefore the change in the longitudes of stars at a given interval from the time of Hipparchus and, consequently, the annual precession, would, necessarily, be less than it ought to be. Ptolemy ascribed the retrogradation of the equinoctial points to a movement in the eighth sphere and, in the Almagest[a], he informs us that, to represent this sphere, he had made a globe on the surface of which he marked the stars with different colours according to their magnitudes, on a dark ground; the ecliptic he says was traced upon it, and the graduations commenced from the circle of longitude passing through Sirius. This globe must have been intended for popular use, and the manner of placing the zero of the longitudes seems to have had some relation to the commencement of the agricultural year: in his catalogue of stars the longitudes are reckoned from the vernal equinox.

In speaking of the earth, Ptolemy repeats the arguments used long before his time to prove its form, he infers its convexity from the fact that, when a ship recedes from a spectator on the shore, the top of the mast appears to descend till it gets below the circle bounding his view, and its sphericity is demonstrated from the magnitudes of the circles which the stars describe by their diurnal motion: he shews that these circles are different from those which would be observed if the earth had been a plane surface or a polyhedral body, and he adds that the circle and sphere are the most proper figures for motion because they contain, respectively, the greatest area and solidity within a given perimeter and superficies. Ptolemy afterwards contends that the earth is at the centre of the universe, compared with which, he says, it is but a point, he denies the possibility of its having a movement of translation or rotation because, he observes, all the bodies on its surface would be thrown from it into space; and it would follow, he thinks, that no cloud, bird or projected body could advance towards the east because it would be left behind

[a] Lib. VIII. Cap. 3.

by the superior velocity of the earth in the same direction. It is remarkable that this opinion should have so long prevailed among the ancients, for it could hardly have escaped observation that, when a ship is sailing, even with the utmost rapidity; the motion of any object thrown from the hand of a person on board is neither retarded when in the same direction as that of the ship's motion, nor accelerated when in the contrary direction; and the reason is that the original impulse is compounded of the projectile force and that resulting from the movement of the ship and, therefore, relatively to the ship, a projected body moves as if the ship were at rest: the composition and resolution of motions may not have been understood in those days, but the circumstance above related must have been known, and it would be very natural to infer that the paths of bodies projected from the earth were, in like manner, unaffected by its motion. Ptolemy, moreover, alleges, in support of his opinion of the quiescence of the earth, that it would be contrary to nature for such a heavy body as the latter to be endowed with motion, and the celestial bodies be at rest, though he grants that a movement of rotation in the earth would facilitate the explanation of many celestial phenomena. The same philosopher, or his commentator Theon, seems to admit the existence of Antipodes for, in speaking of certain phenomena of the heavens, the latter shews how they would be modified with regard to a people so situated.

In the first book of the Almagest Ptolemy gives the result of his researches on the subject of the obliquity of the ecliptic to the equator of the earth, an element admitting of determination from the simplest observations which enter into the practice of astronomy; and it appears that, like Eratosthenes, he ascertained the double obliquity by taking the difference between the observed zenith distances of the sun on the days of the summer and winter solstices: he makes this difference equal to something between $47\frac{2}{3}$ degrees and $47\frac{3}{4}$ degrees, a mean of which is $47° 42' 30''$, differing scarcely 10 seconds from the quantity found by Eratosthenes; though from what we now know of the progressive diminution of that obliquity, the difference, in the interval between the times of the two astronomers, should have

been equal to about $2\frac{1}{2}$ minutes: it is easy, however, to conceive that so small a quantity would be incapable of detection by such instruments as Ptolemy describes; this uncertainty is, consequently, excusable, but it is very remarkable that he should have committed an error of about 15 minutes in the zenith distance of the sun, on the occasion of determining the latitude of Alexandria, which he makes equal to 30′ 58″ north, whereas it is now known to be 31° 13′, and this city, being his place of observation, should have had its geographical position determined with the utmost possible accuracy because of the frequency with which that element enters into his astronomical computations The greatness of the error seems to justify the opinion that, whatever might be the merits of Ptolemy as a discoverer and calculator, he has small claim to that of an accurate observer, indeed it is probable enough that he did not much attend to this part of the science and, even, that he frequently used without enquiry the results of observations which had been made by other persons, perhaps, previously to his own time.

The duration of the tropical year, or the interval between the times of the sun's return to the same equinox or solstice, is the next element of importance in astronomy, and Ptolemy immediately proceeds to ascertain it or, rather, to verify the determinations of Hipparchus with respect to it. The method he pursues is the same as that employed by the latter astronomer, one of whose observations he makes use of for the purpose; this is the time of the arrival of the sun at the vernal equinox in the thirty-second year of the third Calippic period, corresponding to the year 178 from the death of Alexander, or the year 145 before Christ, in the morning, (probably at sunrise) of the twenty-seventh day of the month Mechir, which is the sixth of the Egyptian year, and he compares this observation with one of the same kind made by himself in the year 463 from the death of Alexander, at an hour after noon on the seventh day of the month Pachou, which is the ninth of the Egyptian year. Now the year consisting of 365 days exactly, and being divided into twelve months, of thirty days each, besides the five epagomenæ, or complementary days, and the day commencing at noon, we have, for the time of the equinox observed by Hipparchus, reckoning

from the death of Alexander, 178 years, 176 days and 18 hours, and for the time of that observed by Ptolemy, reckoning from the same epoch, 463 years, 247 days, 1 hour, so that the interval, in years of 365 days each, is 285 years, 70 days, 7 hours; therefore, dividing the 70 days, 7 hours, or 70.291667 days, by 285, the complete number of years, the quotient is 0.246638 day, and the length of the year is equal to 365.246638 days, which is the same as that assigned by Hipparchus, and differs from the truth by about 6 minutes in excess. Ptolemy obtains the same result from a comparison of another equinox observed by Hipparchus with one observed by himself; and, again, from a comparison of the time of a solstice observed by Meton and Euctemon, at Athens, in the year 316 of Nabonasser (431 years Before Christ) with one observed by himself in the year 463 from the death of Alexander (the year 140 of our era); but this exact agreement in the three results has excited a suspicion of the reality of the observations which is, certainly, better founded than that relating to his observations on the fixed stars. For it is remarked by Bailly that an error of six minutes in the length of the tropical year resulting from a comparison of observations distant from each other in time as much as 285 years, corresponds to an error of 15 hours in the time of each equinox; but he considers that so great an error is not likely to have occurred in any actual observation, since the time of the arrival of the sun at the equinox can, always, be estimated within six hours; and he, therefore, concludes that Ptolemy had, while pretending to verify it, only repeated the determination of Hipparchus. Both astronomers differ but little from the moderns in the length they assign to the sidereal year.

Dividing 360 degrees by the length of the tropical year above found, Ptolemy obtained the mean daily motion of the sun; and, hence, computed a table of the mean movements for years, months, days and hours. The epoch is fixed at the first year of Nabonasser, which coincides with the year 747 before Christ.

Ptolemy professes[a] to adopt the ideas of Plato respecting the circular and uniform movements of the sun, moon and planets; and he considers that the apparent variations from that uniformity are caused by the positions of the circles composing those

[a] Almagest, Lib IX. Cap. 2.

spheres which, he observes, *the imagination has conceived in the heavens:* an expression proving that he did not understand the planetary spheres to be material, as has been frequently supposed; and though, in another place, he says the spheres perform their revolutions in directions contrary to that of the fixed stars and about different poles, it is still probable that he considered such poles and spheres to have but an hypothetical existence. Ptolemy adds that the variations in the planetary movements may be explained either by the system of epicycles, or by that of eccentric orbits, but, in his investigations, he has invariably combined the two.

The solar theory, as exhibited by Ptolemy, appearing to be identical, in the values of the elements and, probably, in the mode of investigating them, with that previously proposed by Hipparchus, we have considered it proper to give the explanation of this theory in our account of the works of that great astronomer; and we have now merely to observe, that neither Hipparchus nor Ptolemy take any notice of the movement of the solar apogeum in space; it would seem, therefore, that both of them supposed it to have always the same position with respect to the fixed stars, which would imply that it had a motion equal, and in a contrary direction, to that of the equinoctial points. Now the movement of the apogeum in one year is known to be about 62 seconds in that contrary direction; consequently it moves forward, or from west to east, 12 seconds in the same time, with respect to the fixed stars; and, in the interval which had elapsed between the times of Hipparchus and Ptolemy, the apogeum must have advanced in longitude about 48½ minutes, which, necessarily, vitiates the values assigned by Ptolemy to the sun's anomaly: and, as a comparison of the place of the sun given by the tables, for any particular time, with the place found by observation at the same time, would have shewn the errors of the tables; it is evident that the astronomers of that day must have neglected to verify the theory by making such comparisons, or must have disregarded the differences which they may have detected. When, by the solar theory, the sun's daily longitude could be ascertained by computation; the obliquity of the ecliptic to the equator having been also found, as we have shewn; the rules of spherical trigonometry, which

were known in the times of Hipparchus and Ptolemy, enabled those astronomers to calculate, also, the sun's daily right ascension and declination, and these three elements probably entered into the first ephemerides which were published.

The length of the apparent astronomical day and the causes of its variations are supposed, as we have observed, to have been well known to Hipparchus; but Ptolemy appears to have been the first who formed a table of those variations for the purpose of readily reducing any given interval expressed in apparent, to the value of the same interval in mean solar time, or the converse. He adopts, for the length of a mean solar day, the time in which a point of the celestial equator would revolve about the earth, through the entire circumference of a circle and as much more as is equal to an arc which measures the sun's mean daily motion in right ascension, or in longitude; and he shews that the true solar day is equal to the time in which the sun revolves about the earth through the circumference of a circle and as much more as is equal to an arc which measures the sun's true movement in right ascension in the interval; evidently therefore, the difference between the true daily motion of the sun in right ascension, for a given day, and the mean daily motion either in longitude or in right ascension, must be the difference between the lengths of the apparent and mean solar days; and these being found for every day of the year, by continual addition the table of the daily equation of time was formed. It is not likely that this important element should have escaped the notice of so acute a philosopher as Hipparchus; and, as Delambre observes, since Ptolemy no where mentions that the former had neglected to apply the correction in his researches, there can be no doubt that he was fully acquainted with its cause and the rule by which it might be computed.

In the fourth book of the Almagest, Ptolemy explains the theory of the moon, a subject which has always presented great difficulties to astronomers, from the many perturbating causes which have sensible effects on her movements, and which, till lately, were very imperfectly known. We have shewn that Hipparchus had determined the radius of the moon's epicycle or, as we should call it, the eccentricity of her orbit, the maximum

equation of her centre and the place of her apogeum, all which elements were then considered as constant quantities: with the knowledge of these, and of the several mean movements of the Moon, Ptolemy determined that, at the epoch of Nabonasser, which is fixed at the noon of the first day of October in the year 747 Before Christ, the moon's longitude was $1^s\ 11^\circ\ 22'$; her anomaly, $8^s\ 28^\circ\ 49'$; the difference of longitude between the sun and moon, $2^s\ 10'\ 37''$, and the place of the ascending node, $10^s\ 24^\circ\ 23'$. These elements constituted the basis of the lunar tables then in use, and they seem to have been determined entirely from the data furnished by the researches of Hipparchus, though it may be that Ptolemy had verified or corrected by new comparisons the results established by the former astronomer: on one occasion, however, he has not been fortunate, for, comparing an eclipse observed at Babylon in the year 491 Before Christ with one said to have been observed by himself above 615 years later, the moon being, at both times, at equal distances from the opposite nodes, he has deduced a value of the mean diurnal motion with respect to the nodes differing from that given by Hipparchus and, in consequence, he has applied a correction to that motion which increases the error previously existing.

The equation of the moon's centre or, as it is also called, the principal inequality of the moon, was ascertained, as we have shewn, by comparing the mean place of that luminary with its true place at the time of an eclipse; and the correction so found was probably considered by Hipparchus to hold good when the moon is in any situation with respect to the sun; but we are indebted to Ptolemy for the discovery of the fact that it is only applicable when she is in syzygy; he perceived that, then, her place, found by direct observation, agreed very nearly with that obtained from the tables, the error being only such as might, with great appearance of probability, be ascribed to the imperfection of the instruments or to some uncertainty in the value of the moon's parallax: it might have been remarked, also, that the observed and calculated places agreed nearly when the moon was dichotomised, provided she were in the apogeum or perigeum of the epicycle, because there is, then, no equation of the centre; but in every other situation of the moon, the places

differed, and Ptolemy found the error to be the greatest when the moon was in quadrature upon the epicycle; that is, when her anomaly was about 90 degrees: the observed longitude was less than that given by the tables when the prostapheresis, or the former equation, was subtractive, and greater, when additive; and he found that the error was nearly proportional to the equation itself. Hence Ptolemy, in order to explain this second inequality of motion, was led to suggest the following modification of the lunar system.

He supposes E (Plate II. fig 4) to be the earth or centre of the universe; about E as a centre he imagines a circle, C C′ C″, to be described on whose circumference moves, in retrograde order, or according to the order of those accented letters, the centre of another circle called the eccentric, having its radius equal to the mean distance of the moon from the earth, let A D′ be one position of this circle and A′ D another; and, on the circumference of the eccentric let the centre of the epicycle move in direct order, or from A towards D′. Now, in consequence of the movement of the centre of the eccentric, the apogeum, A, of the same eccentric, moves in retrograde order, or from A towards D, as if it moved upon the circumference of a circle imagined to pass through A, D and G, and having E for its centre; and the centre of the epicycle seems to move upon the periphery of an oval figure, as A A′ G.

The sun, S, is supposed to revolve about E with his proper motion, in direct order; the moon, to revolve in her epicycle, in the same manner with her mean anomalistic velocity; and the mean syzygies take place whenever the centre of the epicycle is in the line joining E and S: now the daily movement of the apogeum of the eccentric, from A towards D, is supposed to be equal to 11° 12′; and the motion of the centre of the epicycle is supposed to be 13° 11′ daily (the mean daily motion of the moon in longitude) from A towards D′; hence, the sum of these movements is a daily angular velocity about E, equal to 24° 23′, by which the centre of the epicycle recedes from the apogeum of the eccentric, and this is equal to twice the mean synodical movement of the moon. therefore the excess of the velocity of the centre of the epicycle above that of the apogeum of the

eccentric will, in half a synodical revolution of the moon, cause these points to come in conjunction, so that a line joining them will pass through the earth: and if the sun was in the direction of the same two points, as at S, at the commencement of the motion, it will again be in a line drawn through them, as at S′, at the end of that time; the angle S E S′ being equal to that described by the sun in the said half synodical revolution. In like manner, the apogeum of the eccentric, the centre of the epicycle (or the mean place of the moon) and the sun, will be in a line passing through the earth at the end of a complete synodical revolution of the moon. By this hypothesis the centre of the epicycle is always brought to the apogeum of the moveable eccentric, that is to the same distance from the earth at the times of syzygy; and this being the constant distance supposed by Hipparchus, it follows that the equation of the moon's centre is, then, the same as he made it, whatever part of her epicycle the moon be in; and if she be at the quadrature of the epicycle, as at M; that is, if her anomaly be 90 degrees, the equation in that position of the epicycle, is the greatest, and it was found, by the last mentioned astronomer, to be equal to 4° 59′ 2″, as we have shewn, though Ptolemy makes it 5° 1′.

But in the same hypothesis, at the times of syzygy, the moon in her epicycle is always in the line joining the sun and earth, or in that line produced; the major axis A G of the oval figure A A′ G is always directed, either accurately or nearly, to the sun, at the same time; and, hence, we may suppose that figure to revolve about E with a movement equal to that of the sun: it follows that the moon, at the time she is dichotomised is, in some part of her epicycle, either accurately or nearly in a line, as X Y, passing through E at right angles to the position of the axis at that time; therefore the radius of her epicycle will then subtend a greater angle, at the earth, than when its centre is in any other part of the oval; and if the moon's anomaly be 90 degrees at that time, or she be in quadrature on her epicycle, as at M′, the value of that angle is a maximum, and Ptolemy, by a comparison of the moon's observed longitude, when in that situation, with her mean longitude, found it equal to 7° 40′. But it is evident that if the moon, thus dichotomised, were in the

apogeum or perigeum of the epicycle, as at N or N′, her true longitude should coincide with her mean longitude, which is that of the centre of the epicycle, and there ought to be no equation, as was observed above.

A mean of the above two greatest equations of the moon's centre, at M and M′, is equal to 6° 20′ 30″: this may be considered as the mean equation and it approaches very near the value assigned to this element by modern astronomers, who make it equal to 6° 18′. The difference between this mean equation and the greatest above mentioned is 1° 19′ 30″, which constitutes the mean value of the second inequality in the moon's motion. To this inequality the name of evection was subsequently given, in the modern astronomy its mean value is made equal to 1° 20′, which is remarkably near the ancient determination of that element.

The computation of the diameters of the homocentric and eccentric circles, and of the epicycle is, now, sufficiently easy. Ptolemy supposes E (Plate II. fig. 3) to be the earth, A and X to be the centres of the epicycles when in the apogeum and perigeum, respectively, of the oval figure; and A m and X n, which are equal to one another, to be radii of the epicycles; then, as above, we have $\angle$ A E m = 5° 1′, $\angle$ X E n = 7° 40′, and the angles at m and n are right angles: hence, assuming E A, the distance of the earth from the apogeum of the eccentric, to be unity, it will be found that the radius of the epicycle is 0 08715, and that E X equals 0.6533; therefore the diameter of the eccentric is 1.6533, and its radius, 0.8266; also, C being the centre of the eccentric, we obtain E C, equal to 0.1734, which is the radius of the homocentric circle, or that whose circumference is described by the centre of the eccentric about the earth. If we assume C A, (fig. 4,) the radius of the eccentric, or the mean distance of the moon from the earth, to be unity, we shall have, for the radius A M, of the epicycle, 0.1055, and for E C, that of the homocentric, 0.2098; which is, therefore, nearly double the radius of the epicycle.

In finding the difference between the mean and apparent places of the moon from observation, that is, the angle at the

earth between the centre of the epicycle and the place of the moon in its epicycle, Ptolemy obtains, from astronomical tables, the angular distance between the mean longitude of the moon and the true longitude of the sun for the given time, and adds or subtracts the elongation in longitude, of the moon from the sun, found by observation with the astrolabe, by these means he gets the angular distance in longitude between the mean and true places, of the moon, which includes both the equation of the centre and the evection. To find the place of the mean apogeum on the epicycle, he draws a line through the earth E, and C′, the centre of the eccentric; then from the point C‴, where this line intersects the homocentric on the opposite side, he draws another line through A′, the centre of the epicycle, the point n will be the mean apogeum required; that is, the point from whence the mean anomaly is to be reckoned. The apparent apogeum of the epicycle is at the point n′, where a line from E drawn through the centre of the epicycle cuts the opposite part of the circumference.

Ptolemy asserts that he had computed the second inequality from an observation made by Hipparchus, and had found it equal to that which he had obtained from his own; it is, therefore, evident that Hipparchus must have determined the place of the moon when not in syzygy by observations directly made with the astrolabe and, consequently, it is possible that he might have been aware of the existence of this inequality of the moon's movement though we have no account that he had determined its value.

The theory above described served to determine the true place of the moon, at a given time, nearly within the limits of the errors of the ancient observations, but any results obtained from it would be far from according with those of the present day. No new equation was, however, discovered, perhaps the necessity for such was not felt, till the time of Tycho Brahe who, to the two former, added a third, which is at its maximum at the time the moon is in either of the octants (when it may amount to about 36 minutes) and is null both in syzygy and quadrature.

Ptolemy appears to have made some efforts to find the moon's parallax by computing her zenith distance at a given time, when she would be on the meridian, and comparing it with the zenith distance actually observed at that time: but two such comparisons gave, for the horizontal parallaxes, 22′ 28″ and 68′ 33″, both erroneous, and it is evident that the method must have afforded very uncertain results. but, having found the distance of the moon when in apogee, from the earth, probably by the method we have explained in Chap. X., to be $64\frac{1}{6}$ semi-diameter of the latter, the resulting parallax must have been about 53′ 30″, which is near the truth. He afterwards attempts the distance of the sun from the earth by the method explained in that chapter, supposing the visible semi-diameter of the sun and moon to be, each, equal to 15′ 40″ and the semi-diameter of the earth's shadow in the region of the moon, when the latter was eclipsed in apogee, to be $2\frac{6}{10}$ of her semi-diameters, and he finds it equal to 1210 semi-diameters of the earth, which is as far from the truth as the distance found by Aristarchus: by modern observations that distance is equal to 23984 semi-diameters of the earth.

Had Ptolemy been able to detect by his instruments, with any accuracy, the variations of the moon's apparent diameter during one periodical revolution, he would certainly, on comparing them with the variations which according to his theory take place in her distance from the earth during the same period, have discovered that the theory was entirely at variance with nature; inasmuch as his distances are not inversely proportional to the apparent diameters which, by a law of optics, they ought to be: this law was well known to Ptolemy but the uncertainty of his observations probably caused him to remain in happy ignorance of a discrepancy which would have entirely subverted the edifice he had, with so much skill and labour, raised upon the foundations laid by Apollonius and Hipparchus. And it is remarkable that no comparison of that kind seems to have been attempted till the sixteenth century, when Kepler, by means of the law just mentioned, discovered that the orbits of the moon and sun were elliptical. It is, besides, worthy of observation

that no mention is made by any of the Greek astronomers of an annular eclipse of the sun; and, in fact, such a phenomenon would be incompatible with the determination of Ptolemy that the moon's apparent diameter, in apogeo, when it should be the least, is equal to that of the sun; yet we cannot suppose that annular eclipses had not been observed by the Chaldeans or Greeks, and the silence of the ancients on this subject is quite inexplicable.

CHAPTER XIII.

PTOLEMY'S PLANETARY THEORY.

Conditions required in investigating the orbits of the planets.—Determination of the orbits of the superior and inferior planets.—Investigation of the latitudes of the planets.—Imperfection and complexity of the system of Ptolemy.—The inferior planets supposed by Pliny and Vitruvius to revolve about the sun.—Hypothesis of Vitruvius concerning solar attraction.—Seneca's observation on the probable improvement of astronomy.

In the ninth book of the Almagest, Ptolemy enters upon the theory of the planets which, as he has delivered it, consists in a combination of the preceding theories of the sun and moon, with some further modifications for Mercury. He informs us that the observations made by the more ancient astronomers were of three kinds; the times of their stationary appearances; of their risings and settings; and of their appulses to the moon; and he points out the inaccuracies to which they are subject: he remarks that the first kind of observation is uncertain because the slowness of a planet's motion, when nearly stationary, does not permit the time to be marked with precision; he shews that the risings and settings of stars are affected by a serious cause of error arising from the impossibility of seeing them when they are exactly in the horizon, and from the apparent augmentation of their distances which then takes place, and which he attributes to the vapours of the earth; and, lastly, he observes that the phenomena of the appulses do not, from the errors in the computed place of the moon, afford means of determining the positions of the planets with sufficient correctness. On all these accounts it is evident that direct observations of the planets by means of the astrolabe are to be preferred; and from such, were the data obtained by which Ptolemy computes the elements of the orbits In speaking of the apparent situations of celestial bodies when near the horizon, it is remarkable that this astronomer does not mention the refraction of light as a

cause of the augmentations of their altitudes, and distances from each other, and it is probable that, at the time of writing the Almagest, he had not made the discovery of the effect of the atmosphere in changing the directions of the rays of light, which, however, he must have found out soon afterwards, for he has introduced an account of the phenomena resulting from it, in his treatise on Optics, which, fortunately, is still in existence

In the theory now to be described he supposes that the earth is at rest in the centre of the universe; that the planets, and the sun as one of them, revolve about it, he considers Mars, Jupiter and Saturn to be more remote from the earth than the sun is, but he observes, as we have before stated, that there were two opinions concerning the positions of Mercury and Venus, the more ancient philosophers supposing them to be situated between the earth and the sun and to revolve about the former while some, of later times, placed them beyond the sun with respect to the earth; and the first opinion is that which he adopts in his researches. He assumes the truth of the Aristotelian doctrine that the celestial motions are uniform and circular; but he observes that the movements of a planet cannot be explained, either on the hypothesis of a simple eccentric orbit, or on that of an epicycle moving upon a homocentric deferent, which probably constituted the theories of Apollonius and Hipparchus, and the following is an outline of the manner in which he has combined the two hypotheses, to satisfy the phenomena as far as they had then been observed.

Let E (Plate II. fig. 2.) be the centre of the earth and of the universe; and upon any line, as A P, take E C equal to the eccentricity of the planet's orbit; a distance corresponding to E C in the preceding description of the system of the moon. Bisect E C in Z and about Z as a centre describe the circle A M P which is that called the eccentric and which, in the solar theory, would be that on whose circumference the sun moves. The centre M of the epicycle L V V′ moves on the circumference of this circle, and Z is called the centre of mean, or constant distances, for M Z is equal to the mean distance of the planet from the earth. The planet, if superior, moves on its epicycle in direct order, or from V towards T, if inferior, in retrograde order,

or from V′ towards T; but the motion of the centre of the epicycle is always direct, or from A towards M. The angle A C M is always produced by the mean movement of the planet, or the movement of the centre M, of the epicycle is such that, when seen from C, it appears equal to the planet's mean motion in longitude, hence C was called the centre of mean or equable movements, and a circle, as H t Z, described about C as a centre with any radius was called the equant, because the point t, in the line C M, would appear from C to describe its circumference with uniform motion. The above description will serve for all the planets, superior and inferior, except Mercury, in whose system, Z, the centre of the eccentric and of mean distances, moves upon the circumference of a circle described about C as a centre with a radius equal to C Z, the half eccentricity; just as, in the moon's orbit, the centre of the eccentric moves upon a circle described about E as a centre.

The line A C E P is the line of the apsides of the eccentric circle, it was not considered as stationary in space but as having an angular movement about E with a velocity equal to that of the precession; L M C is the line of the apsides of the epicycle, and this tends constantly towards C for all the planets except Mercury. Now let a circle be described about E as a centre, with any radius, to represent the orbit of a fictitious sun, and on its circumference let such a sun be supposed to move uniformly with the mean motion of the real sun, then, as was shewn in the tenth chapter, the mean relative motion of the planet, or that performed in its epicycle with respect to the sun, being equal to the difference between the mean motion of the sun and that of the planet in longitude, if we suppose S′ to be the place of the fictitious sun when the planet is at V′ and in opposition, S′ will be its place at the next time of opposition when the planet will be at V′; it must be observed, however, that E is not supposed to be the centre of the mean movements in the solar orbit, but the error arising from so considering it, is by Ptolemy disregarded in the planetary theory. The angles E M C and E M′ C constitute, for the points M and M′ respectively, what was called the anomaly of the eccentric, the planet's zodiacal, or proper, or first inequality, or the equation of the

centre; and this element corresponds to that, to which in the solar theory, the latter denomination was applied, the second inequality was supposed to depend upon the position of the planet in its epicycle, and was expressed by the variable angle M′ E R, the planet being supposed at R.

The mean tropical revolution of a planet, and the mean revolution in its epicycle had been well ascertained, as we have shewn, before the time of Ptolemy, and the ancient values of these elements differ but little from those assigned to them in the modern tables: we cannot, however, say so much of the equations by which the mean, were reduced to the apparent movements, since the erroneous theory of the Greeks but badly represented the laws of the variations of planetary motion between the periods in which their inequalities are compensated; yet it will be both interesting and useful to shew in what manner Ptolemy determined the elements of the orbits of the planets on the hypothesis which has been just explained. For this purpose, it must be supposed that, besides a knowledge of the mean movements above mentioned, he possessed registers of many observed longitudes and latitudes of the planets at, or near, the times of the opposition of the superior, and the greatest elongations of the inferior planets with respect to the sun; and, from these, by the help of a table shewing the mean solar movements, he was enabled to ascertain the apparent places of the planets at the moments when those places were in opposition with the mean places of the sun. With these elements, by the rules of trigonometry, he found, as we shall explain, the places of the apogea, the eccentricity, the radii of the epicycles and the equations of the centres. The opposition of the true longitude of a planet to the mean longitude of the sun is made use of by Ptolemy because the planet, in this situation, is, according to his hypothesis, at the extremity of its epicycle, passing through the earth, and the second inequality, or that depending on the place of the planet in its epicycle, is, consequently, null It may be observed here that, in the modern astronomy, the oppositions and conjunctions of the planets with the sun are, also, generally employed for investigating the elements of their motions in order to avoid the inequality caused by the distance

of the earth from the centre of the system; but the oppositions or conjunctions are those of the true geocentric longitudes of both sun and planet.

The data employed by Ptolemy in investigating the orbit of Mars were three longitudes of that planet observed by himself in the fifteenth and nineteenth years of Adrian and in the second year of Antoninus, when the apparent places of the planet were in opposition to the mean places of the sun. These longitudes were $2^s\ 21°$, $4^s\ 48°\ 50'$ and $8^s\ 2°\ 34'$ respectively, and the intervals of time were 1530.8333 days, and 1557 0417 days; the mean movements of the planet in the two intervals, according to the tables and rejecting entire circumferences, were $81°\ 44'$, and $95°\ 28'$, respectively, while the observed movements, by taking the differences between the above observed places, were $67°\ 50'$ and $93°\ 44'$. Now let E (Plate III. fig. 1) be the earth, and M, M′, M″ be the three observed places of Mars, in the circle of mean distances whose centre is Z, consequently we have $\angle \text{MEM}' = 67°\ 50'$ and $\text{M}'\text{EM}'' = 93°\ 44'$ as above: let C be the centre of mean movements and describe the circle m m′ m″ about C as a centre with a radius equal to that of the circle of mean distances; draw C M m, C M′ m′, C M″ m″; then m, m′, m″ become the places of Mars calculated by his mean movements, so that $\angle \text{m C m}' = 81°\ 44'$ and $\angle \text{m}' \text{C m}'' = 95°\ 28'$ as above; and let it be required to find the eccentricity E C and the position A P of the line of the apsides. To obtain these, Ptolemy assumes, as known, the length of a line E p, drawn through E and m″, one of the mean places of the planet in the circle of mean movements; and, from this, with the given angles, he computes trigonometrically the value of the radius of the circle of mean distances and, subsequently, the value of the eccentricity in terms of that radius: from the same data he gets the angle made by the line of the apsides with a line drawn from C to one of the observed places of the planet, by which, and the observed longitude of that point, the longitude of the perigeum is determined.

The details of the investigation are as follow. The angles m E m′, m′ E m″ do not differ much from M E M′, M′ E M″; therefore, as a first approximation, Ptolemy supposes them equal, and he produces m″ E to p, the $\angle$ m E p may be considered as

the supplement of the sum of the two observed angles, and therefore, as equal to 18° 26′; consequently ∠ m′ E p is equal to 86° 16′; next ∠ m c m″=177° 12′, the sum of the mean intervals, and its half, which is the angle m p m″, is equal to 88° 36′; also ∠ m c m′= 81° 44′, the first mean interval, and its half, or ∠ m p m′,=40° 52′; consequently ∠ m′ p E=47° 44′ and ∠ E m′ p=46°. Then, assuming E p to be unity,

in the triangle m′ E p, we have E p=1 and all the angles;
to find m′ p [=1·38713];

in the triangle m E p, we have E p=1 and all the angles;
to find m p [=0 33071], and

in the triangle m′m p, we have m′p, m p and ∠ m p m′;
to find ∠ m m′ p [=10° 46′ 26″] the double of which, or ∠ m c p, is equal to 21° 32′ 52″. But to find E p in terms of the radius of the circle m m′ m″, make that radius equal to unity; then, because ∠ m′ c p is known, being equal to the sum of the angles m′ c m and m c p; in the isosceles triangle m′ c p, we have c m′ and c p, each equal to unity, and ∠ m′ c p=103° 16′ 52″; to find m′ p [=1·56826]: also, in the triangle m′ E p, we have m′ p and all the angles; to find E p [=1·13052]. Now the sum of the angles m′ c m″, m′ c m, m c p is equal to 198° 44′ 52″, this taken from 360° leaves the angle m″ c p equal to 161° 15′ 8″; bisect this angle by the line c N which, therefore, will bisect m″ p at right angles in N; then in the triangle m″ c N we have c m″=1, ∠ m″ c N=80° 37′ 34″ and the right angle at N; to find m″ N, or N p, [=0·986674] and c N [=0·16288]; whence E N [=E p—N p] is found to be 0·14387, and from the right angled triangle c N E we can find c E [=0·217344]; this, consequently, is the value of the double eccentricity when the mean distance of Mars from the earth is equal to unity. Now the complement of the angle E c N is equal to ∠ c E N or ∠ m″ E P which, for the present, may be considered the same as the angle M″ E P; to this add 8ˢ 2° 34′ the observed longitude of M″, and we shall have 9ˢ 21° 7′ for the longitude of P, the perigeum of the eccentric; hence the position of the line A P, of the apsides, is known approximatively. The same elements may then be re-computed from the more correct data afforded by the preceding determinations, which depend

upon the erroneous assumption of the equalities of the angles m′ E m, M′ E M and the angles m′ E m″, M′ E M″: in the second approximation Ptolemy concludes that the longitude of the perigeum of the orbit of Mars was then equal to $9^s\ 25^\circ\ 30'$ and that the eccentricity, C Z or Z E, was 0·1, the mean distance being unity.

Ptolemy afterwards computed the angular distance of the planet from the mean apogeum of the epicycle when not in opposition with the sun, and with that, proceeded to find the radius of the epicycle itself For this purpose he uses an observation made three days after the last of the preceding oppositions, the mean longitude of the sun being $2^s\ 5^\circ\ 27'$, the observed longitude of Mars, determined by his distance from Spica Virginis, $8^s\ 1^\circ\ 36'$, and the longitude of the perigeum of the eccentric $9^s\ 25^\circ\ 30'$ as before found; the difference between the last two quantities, which is $53^\circ\ 54'$, gives the distance of Mars westward from the perigeum The true longitude of Mars at the time of the last opposition was $8^s\ 2^\circ\ 34'$, and the planet was then at V, on its epicycle, the mean place of the sun being supposed to be in the line M″ E produced towards p Now the difference between the longitude of P, the perigeum, and of M″, or V, is $52^\circ\ 56'$, which is equal to the angle M″ E P; but the angle m″ C N, after the second correction is $81^\circ\ 25'$; therefore its complement, the angle C m″ E is equal to $8^\circ\ 35'$ or, as Ptolemy makes it, $8^\circ\ 22'$, and this taken from ∠ m″ E P leaves ∠ m″ C P equal to $44^\circ\ 21'$, and its supplement, or ∠ A C m″, equal to $135^\circ\ 39'$, the mean distance of Mars from the apogeum of the eccentric at the time of the said opposition. By the mean daily motion of Mars in longitude, his movement in the three days since the opposition, is found to be $1^\circ\ 32'$, if, therefore, the angle M″ C M‴ be made equal to this quantity we shall have M‴ for the place of the centre of the epicycle at the time of the present observation, and the angle A C M‴ will be equal to $137^\circ\ 11'$ next draw M‴ E cutting this epicycle in V′, then, by the planet's mean daily motion in the epicycle, his movement in the three days is found to be $1^\circ\ 21'$, and the angle V′ M‴ R being made equal to it, R becomes the place of the planet; we have therefore the arc v V′ R equal to $181^\circ\ 21'$, and from this, taking what is called the anomaly of the eccentric which is the angle C M‴ E,

or its measure, the arc v v′, [supposed to be 8° 35′ as above] the remainder [=172° 46′] is the value of the angle v′ M‴ R, the distance of the planet from the mean apogeum of the epicycle. In finding the radius of the epicycle, the mean distance M‴ Z is assumed equal to unity; then, in the triangle C M‴ Z, we have M‴ Z=1, C Z [the half eccentricity]=0·1 and ∠ M‴ C Z=12° 49′; to find the angle C M‴ Z [=3° 53′ 53″]; whence the angle E Z M‴ becomes known [=46° 42′ 53″]; we have also ∠ Z M‴ E [=∠ C M‴ E−∠ C M‴ Z] =4° 28′ 8″; and the angle v M‴ v′, which Ptolemy now makes equal to 8° 22′ 1″, added to the angle v′ M‴ R [=172° 46′], gives, for the arc v V″ R, 181° 8′ 1″; whence ∠ V″ M‴ R= 1° 8′ 1″. Now the sum of the angles M‴ C E and C M‴ Z is equal to the angle M‴ Z E [=46° 42′ 53″], and if again to this we add ∠ Z M‴ E, the sum [=51° 11′ 1″] is equal to the angle M‴ E P; this taken from ∠ P E R [=53° 41′] which is the above mentioned distance of Mars from the perigeum of the eccentric, gives the angle M‴ E R [=2° 42′ 59″]; whence, by adding ∠ V″ M‴ R, we have the supplement of ∠ M‴ R E [=3° 51′]. Let fall E a perpendicularly on M‴ Z; then Z a [=0·0686] may be found in the triangle Z a E, and we shall have M‴ a=0·9314: wherefore, in the triangle E a M‴, we obtain M‴ E [=0·93424]. Lastly, in the triangle M‴ R E, we have M‴ E and the angles; to find M‴ R [=0·65638], the required radius of the epicycle; but it has been with justice observed that Ptolemy has chosen a very unfavourable situation of the planet for determining this element, on account of the smallness of the angle M‴ E R. By similar processes the elements of the orbits of Jupiter and Saturn were found: he makes their eccentricities equal to 0·0458 and 0·0542 respectively, and the radii of their epicycles 0·192 and 0·105, the mean distances of the planets from the earth being supposed equal to unity. From the theory of gravitation it is found that, in the age of Ptolemy, the eccentricities of Mars, Jupiter and Saturn were 0·09183, 0·04552 and 0·06124 respectively; the errors, therefore, are not so great as might be expected.

Ptolemy's theory of the inferior planets is contained in the tenth book of the Almagest; and in the investigation of their orbits he considers the conjunctions to be made by the equality

of the longitudes of the planet's apparent place and the sun's mean place, as in treating of the orbits of the superior planets: he also considers that the centre of the epicycle of an inferior planet always coincides with the mean place of the sun at any given time, and that the apogeum of the eccentric represents the situation of the mean sun at the middle point of time between those at which the elongations of the planet from the mean place of the sun are equal to each other but on opposite sides of the sun.

Therefore to fix the position of the apogeum in the eccentric of Venus, it was only necessary to take from the registers of observations two longitudes of the planet of which one exceeded the mean longitude of the sun, found from the tables of the sun's movements, as much as the other was deficient: but, by an observation of the elder Theon in the twelfth year of Adrian, Ptolemy finds the elongation of Venus westward of the mean place of the sun to be 47° 32′, when the latter was in 6^s 17° 52′, and by an observation which he, himself, had made in the twenty-first year of Adrian, he finds the elongation eastward to be 47° 32′ when the sun's mean longitude was 9^s 2° 5′, the longitude of the middle point between those two places of the sun is evidently equal to 7^s 25° nearly, and that of the opposite point, 1^s 25°, and since the sun was nearly in apogeo when his mean longitude was 1^s 25°, this point is to be considered as the apogeum of the eccentric circle of Venus, and the former as the perigeum.

To obtain the eccentricity and the radius of the epicycle, Ptolemy takes two observations from each of which the extreme elongations might be obtained when the mean places of the sun were 1^s 25° and 7^s 25°; that is, when the mean sun was in the apsides of the eccentric of Venus; the first of these observations is in the thirteenth year of Adrian when, the mean sun being in apogeo, the extreme elongation was 44° 48′ westward, and the second in the twenty-first year of Adrian when, the mean sun being in perigeo, the extreme elongation was 47° 20′, also westward: with these data he proceeds to investigate the elements in the following manner. Let A N P [Plate III. fig. 2.] be the eccentric circle of which Z is the centre; let, as

before, E be the earth and C the centre of mean or uniform motions; then A and P will be the places of the apogeum and perigeum respectively; these points will also represent the mean places of the sun when in the apsides of the eccentric, and let it be observed that Ptolemy supposes this circle to be fixed in space, or that the line of the apsides is subject only to the motion of precession. Take V and V′ to represent, at the two times of observation, the places of Venus in the epicycle, which are where the tangents E V and E V′ meet its circumference; then since A V = P V′, we have, in the right angled triangles A V E and P V′ E, A E : E P :: sin. ∠ P E V′ : sin ∠ A E V then, the half sum and half difference of these angles of elongation being known, as above, to be 46° 4′ and 1° 16′ respectively, we have, using the modern trigonometry to avoid the laborious processes of Ptolemy,

$$\text{tang. } 46^\circ\ 4' \ .\ \text{tang. } 1^\circ\ 16' :: AE+EP : AE-EP:$$

whence, assuming A Z, the mean distance of Venus from the earth, to be unity, it will follow that A E + E P = 2, and A E − E P = 0·042606, which is equal to the double eccentricity, therefore the eccentricity E Z is 0 021303: then also A V, or its equal P V′ [= 0 71965] may be found from the triangle A E V. The radius of the epicycle of an inferior planet may be considered as the mean distance of that planet from the sun, and, for Venus, the value of this mean distance according to La Place is equal to 0 72333, which differs but little from the determination of Ptolemy; the eccentricities, however, do not agree so well, for, by the theory of gravitation, that of Venus was, in the age of Ptolemy, only equal to 0·00789, which is little more than one third of the value above obtained.

In order to find the maximum equation of the centre, Ptolemy chose two observations, made when the elongation of Venus from the mean place of the sun was the greatest, and when the mean place of the sun was at 90 degrees from the apogeum of the planet's eccentric; that is, when his mean longitude was $10^s\ 25^\circ$: the first of these was in the eighteenth year of Adrian, when the geocentric longitude of Venus was $9^s\ 11^\circ\ 25'$ and, consequently, her elongation was 43° 35′ westward, and the second was in the third year of Antoninus, when the geocentric longitude was $0^s\ 13^\circ$

20′, and, consequently, the elongation was 48° 20′ eastward. At these times the centre of the epicycle must have been at the extremity, N, of a line drawn through C, the centre of mean movements, perpendicularly to the line A P, of the apsides; and V and V′, at the points of contact of the lines E V and E V′, must have been the places of the planet in the epicycle. Now let Q O be an arc of the celestial sphere, and let N be transferred to N′ in that sphere by a line from C, then N′ will represent the mean place of the sun in the same sphere; also let V, N and V′ be transferred to O, to N″ and to Q, by lines from E, then these will be the apparent places of those points: the arcs of elongation in the celestial sphere are O N′ and N′ Q respectively, and half the difference of these [= 2° 22′ 30″] is evidently equal to the arc N′ N″ which may be considered as the measure of the angle N′ N N″ or C N E, the equation required.

It is proper to remark here that Ptolemy corrected the mean movement of Venus and the place of her apogeum by comparing a geocentric longitude of the planet, observed by himself in the second year of Antoninus, with one observed by Timocharis in the thirteenth year of Ptolemy Philadelphus, the interval being 409 years 167 days, during which time the planet had described 225.93986 revolutions in the epicycle. From hence he finds the mean daily motion in the epicycle to be 0 61608 degrees, which is rather less than the value found by Hipparchus, and he, afterwards, determines the longitude of the apogeum for the epoch of his tables, which is the first year of Nabonasser, to be 1^s 16° 10′: the mean longitude of the planet is, of course, the same as that of the sun at the same period.

A process very similar to that employed in determining the orbit of Venus was adopted in investigating that of Mercury For fixing the longitude of the apogeum of the eccentric, Ptolemy selected two observations of the planet when the elongations from the mean place of the sun were equal but on opposite sides, one of these was made in the sixteenth and the other in the eighteenth year of Adrian, and at the first, by the distance of Mercury from a fixed star whose longitude was known, the apparent or geocentric longitude of the planet was found to be 11^s 1°, when, by the solar tables, the mean longitude of the sun

was $10^s\ 9° 45'$; the difference which was equal to 21° 15′ and a maximum, was the elongation of the planet eastward: at the second, Mercury's apparent longitude was found in the same manner to be $1^s\ 18° 45'$, when the sun's mean longitude was $2^s\ 10°$, the difference, which was also 21° 15′, and a maximum, was the elongation westward: the middle point between the two mean places of the sun; that is a point whose longitude was $0^s\ 9° 52'$ was the required place of the apogeum of the planet's eccentric. By another pair of observations made in the first and fourth years of Antoninus the place of the apogeum was found to be in 0^s 10° 15′; and a mean between the two places thus determined gives $0^s\ 10° 3' 45''$ for the longitude of the apogeum.

In order to find the eccentricity and the radius of Mercury's epicycle, Ptolemy takes several observations made directly on the planet when the mean longitudes of the sun were the same as those of the apogeum and perigeum of the planet: two of these, which were made by himself in the nineteenth year of Adrian, gave for the greatest elongation, in the first case 23° 5′ eastward, and, in the other, 19° 3′ westward; the sun's mean longitudes being respectively $0^s\ 11° 15'$ and $6^s\ 9° 15'$: but two other observations, made in the fourteenth year of Adrian and in the second of Antoninus, when the mean longitude of the sun was $3^s\ 10°$ nearly, and, consequently, when the sun was at the distance of a quadrant from the apsides of Mercury's eccentric, gave for the greatest elongations 26° 15′ eastward, and 20° 15′ westward, respectively, and Ptolemy takes a mean of these, or 23° 15′, for the maximum elongation in both situations. Other observations made when the mean sun was differently situated gave different elongations, which were not reconcileable with the hypothesis adopted for the orbit of Venus, and it seemed evident, either that the radius of Mercury's epicycle was variable, or that the distance of its centre from the earth was subject to a change, independent of that arising from its motion on a simple eccentric. Ptolemy adopts this opinion and modifies the former hypothesis by making the centre of mean distances moveable, as will be presently explained.

Let E [Plate III fig. 3] be the earth; A B p, a b q and P C I be certain positions of Mercury's eccentric; and let A P be the

line of the apsides. Take C the centre of mean movements, and draw C T perpendicular to A P; then the centre of the epicycle will be in the line C T, suppose it at T, at the times of the two last mentioned observations. At those times half the difference of the two elongations was equal to three degrees which, as was shewn in the orbit of Venus, constitute the amount of the zodiacal inequality, or the angle E T C, hence E C may be expressed by C T. tang. 3°, but, considering M to be the place of the planet in its epicycle, T M to be perpendicular to C M, and ∠ T C M equal to the mean elongation [23° 15′], we shall have C T. sin 23° 15′ = T M, whence, assuming T M to be unity, C T will be found equal to 2.53329, and E C equal to 0.13276. Now, by the observations in the nineteenth year of Adrian, as above mentioned, when the maximum elongation at A, that is the angle A E V, was 19° 3′; and at P, that is the angle P E V′, was 23° 5′, assuming the radius of the epicycle to be unity, Ptolemy found that E A was equal to 3.06379 and E P, to 2 53329: half the sum of these values gave A Z, or Z P [= 2 79854] consequently E Z is equal to 0.26525, which is twice the value of E C. Therefore it is proved that Z is situated at a distance from C, the centre of mean movements, equal to E C but on the opposite side Now, to preserve the above value of T C and to have the centre of the epicycle always equally distant from the centre of mean distances, Ptolemy found it convenient to suppose that this last centre revolved on the circumference of a circle described about Z, with a radius equal to Z C or E C; then, imagining the centre of mean distances to be at Z′ when the centre of the epicycle was at A, and causing the former centre to move in retrograde order, or from Z′ through Z″, on the circle described about Z, while the centre of the epicycle moved in direct order, or from A towards T, with an equal angular velocity; the centre of mean distances would arrive at C when the centre of the epicycle was in perigeo, in the line A P and the eccentric circle would successively take the positions a b q, P C I when the centre of mean distances was at Z″ and C, respectively. A Z′, the mean or constant distance is evidently equal to 2 66578 [= A Z−Z C]; and if we make this equal to unity we have, by proportion, T M, the radius of the epicycle, equal to 0.37513 and E C, the eccentricity, equal

to 0.0995, or nearly one tenth of the mean distance: in the modern astronomy the semiaxis major of Mercury's orbit, which corresponds to the radius of the epicycle in the theory of Ptolemy is equal to 0.3871, and the eccentricity, to 0.2054, the mean distance of the sun from the earth being unity.

The differences in the apparent elongations of an inferior planet, when the mean sun, or the centre of the epicycle, is in different parts of the eccentric, are sensible also in Venus but are not so considerable as in Mercury, they are evidently caused by the ellipticity of the real orbit of the inferior planet about the sun, and the orbit described by the centre of the epicycle according to the hypothesis above explained, produces an approximation to the law of those variations inasmuch as the path of that centre is an oval figure symmetrical on each side of A P, as in the orbit of the moon, by which the radius of the epicycle subtends a variable angle at the centre of mean movement as well as at the earth; and, if it had not been that the prejudice in favour of circular motions overpowered every consideration, the figure of this path must have suggested to Ptolemy the idea of an elliptical orbit, which would have considerably simplified his theory of planetary movement even though he had still supposed the earth to be at rest. It must be, also, observed that, notwithstanding the complexity of the orbits of the planets, the observed inequalities of their motions were far from being accurately represented.

By comparing the longitudes of the apogea of all the planets, found in his own times, with those determined from more ancient observations, Ptolemy concludes that the lines of the apsides are fixed in space and that the longitudes of the apogea appear to increase continually by the mere effect of precession: now we have shewn how erroneously this last element was estimated, and we know that the progression of the apogeum is different for all the planets; that of Saturn, which is the greatest, amounting to about 20 seconds annually with respect to the fixed stars, or to about 70 seconds with respect to the equinoxes; and, as such movements might have been detected in observations made at the end of long intervals of time, there is a presumption that Ptolemy did not attempt the investigation. A

suspicion has, also, arisen respecting the reality of the observations he professes to have made on the inferior planets for determining their elongations from the mean place of the sun, on account of the improbability that the values of those elongations should, as he has asserted, be exactly equal to each other; but this circumstance admits of a reasonable explanation which leaves no ground to doubt the fidelity of the Alexandrian astronomer, for it is conceivable that he would have taken from the registers of observations, made by himself or others, such as occurred near the times when, by the tables, the mean longitude of the sun was any given quantity, and then, by proportion drawn from the daily or hourly movement of the planet, supposed to be previously and approximatively known, it would be easy to ascertain those longitudes of the sun and planet which render the elongations coincident in quantity. Methods similar to this are, even now, employed by astronomers in determining the elements of the orbits of the sun, moon and planets.

In all the reasonings above exhibited the planets have been supposed to move in the plane of the zodiac, or of the sun's apparent orbit about the earth. Ptolemy, however, was well aware that they were sometimes above and, at other times, below that plane: he was aware, also, that the latitude, like the longitude, was subject to two inequalities, and, in the thirteenth book of the Almagest, he enters into an explanation of that part of the planetary theory. He supposes the plane of the eccentric of each planet to be inclined to that of the zodiac; the plane of the epicycle to be inclined to that of the eccentric, and the line of nodes produced by the intersection of the eccentric and zodiac to pass through the earth at right angles to the line of the apsides of the former. The first of the inequalities of latitude he calls zodiacal, and makes it depend on the position of the centre of the epicycle, the other which he calls solar, arises from the position of the planet in the epicycle.

To exhibit the positions of the circles and the manner in which the variations of latitude take place; let XY [Plate IV. fig. 1.] be the plane of the ecliptic, UV that of the eccentric circle for any superior planet; let E be the earth and RES the line of the nodes, or the intersection of the eccentric and ecliptic. Also let

a plane pass through E perpendicularly to the line of the nodes; its intersection with the eccentric gives P A, the line of the apsides and, with the ecliptic, gives P′ A′, the projection of that line; and the angle A E A′ is the invariable inclination of the two planes. Let A be the centre of the epicycle when in apogee, then the plane of the epicycle will intersect that of the eccentric in M N perpendicularly to A P, and let K A Q be that diameter which lies in the plane passing through P A and P′ A′; the angle K A E will be the greatest inclination of the epicycle to the eccentric

Now when, by the mean motion of the planet, the centre of the epicycle moves towards R, the diameter K Q turns about that centre, and its inclination to the plane of the eccentric continually diminishes till, when the centre is at R, the line K Q coincides with K′ Q′ in the line of nodes and the plane of the epicycle coincides with that of the ecliptic, so that the planet, in any part of the epicycle has, now, no latitude: during this movement of the centre the diameter M N, of the epicycle, which is perpendicular to K Q, moves parallel to the plane of the ecliptic and, at R, it coincides with it, and takes the position M′ N′, parallel to P′ A′. As the centre of the epicycle moves from R towards P, the line K′ Q′ continues to turn, and becomes inclined to the ecliptic; and, when the centre has got to P, it coincides with Q″ K″ which is parallel to K Q, the diameter M″ N″, also, which remains parallel to the ecliptic, is now perpendicular to P A.

The angles K E A′ and P′ E K″, which are those of the greatest northern and southern geocentric latitudes of the planet, being given by observation, the radius of the epicycle and the distances of its centre from the earth being also known, as above explained, Ptolemy finds the inclinations A E A′ and K A E. The former is evidently equal to the maximum of the first inequality of the planet's latitude, and, when the centre of the epicycle is in any other part of the eccentric, its latitude will, of course, be expressed by the product of the angle A E A′ multiplied into the sine of the angle which the line of the nodes makes with one drawn from E to the actual place of that centre. The angle K A E also diminishes when the centre of the epicycle changes its place, in the proportion of radius to the sine of the angle above

mentioned; and the sum of these two variable angles gives the value of the latitude in any part of the planet's orbit.

For the latitudes of the inferior planets Ptolemy proposes a similar hypothesis; but he supposes the inclination of the eccentric to the ecliptic to be so small that it may be disregarded, and he gives to the plane of the epicycle a double inclination to the plane of the eccentric or rather, of the ecliptic, so that the lines K Q and M N, of the apsides of the epicycle, may be sometimes in the plane of this circle and, at other times, above or below it, and he exhibits this double and variable inclination by giving to the lines K A Q and M A N conical movements upon A as a vertex, as if the points K and N turned upon the circumferences of two small circles perpendicular to the plane of the eccentric and having their centres in that plane, in such a manner that when either line lay in the eccentric the other might, at one end, be at its greatest elevation above that plane and, at the other end, as much below. This contrivance, of a double inclination, or as Ptolemy expresses it, of an inclination and obliquation was, as Delambre observes, rendered neccessary by that variation in the place of the centre of mean distances which has been described in speaking of Mercury's orbit, for by thus, alternately, bringing the planet nearer to, and carrying it further from the earth than it would be if the centre of the epicycle moved upon a simple eccentric, its geocentric latitude would be augmented and diminished nearly in proportion to the variation of its distance, which is contrary to the phenomena observed; and the conical movement of the radii of the epicycle was thought capable of correcting the error. Knowing the dimensions of the eccentric and epicycle, with the observed geocentric latitudes of the planet when at K and M, it was easy to determine the inclinations of the two diameters of the epicycle to the plane of the ecliptic and the diameters of the small circles on whose circumferences those points K and M were supposed to move. In the orbit of the moon, the plane of the epicycle is supposed to coincide with that of the eccentric; and the inclination of this plane to the ecliptic was found by the method shewn in the explanation of the lunar theory[a]. The errors in the places of the planets when

[a] Chap. XI.

computed by the hypothesis proposed by Ptolemy, for the purpose of exhibiting the variations of their movements both with respect to longitude and latitude were, probably, within the limits of those of the observations made in his age, but they will be found too great, when a comparison is made of the places thus computed with those obtained from modern observations, to permit the system of Ptolemy to stand in competition with that which is now received; and, indeed, the former is worthy of notice chiefly on account of the ingenuity displayed in the various devices adopted to produce an accordance between the deductions from theory and the results of observation. The machinery of the heavens which is described in the works of Ptolemy appeared even to that astronomer somewhat complicated, and he endeavours[a] to apologise for it by observing that we ought not to judge of celestial things by our ideas of simplicity, which are not perfectly fixed and certain, but rather by ideas drawn from the perfection and immutability of the celestial motions themselves; according to which, as he alleges, the most complex subjects may appear more simple, in reality, than those which, to us, seem to possess that quality in the highest degree.

The ancient philosophers having no means of determining the relative distances of the earth, sun and planets, and not being able to distinguish the phases of Mercury and Venus, which shew them to be alternately beyond the sun and between it and the earth, could have no evidence to disprove the opinion that the revolutions of all the planets respected the earth as a centre rather than the sun: yet about the time of Ptolemy, if not, as we have already hinted, (Chap. IV.,) much more anciently, a system must have been popular which, in the positions it assigns to the orbits of the inferior planets, has some resemblance to that invented by Tycho Brahe in a later age. This appears from a passage in Pliny[b] where the writer, endeavouring to give a reason why the last mentioned planets did not deviate far from the sun, says it is because their circles return upon themselves and have that part below the sun which the others have above: now these circles can only be the epicycles, in which the planet

[a] Almagest, Lib. XIII cap: 2 [b] Nat. Hist. Lib. II. cap. 17

moving, when it arrives at the point where a visual ray from the earth is a tangent to the orbit, it appears to return towards the sun; and the part said to be above the sun is, doubtless, the perigeum which, in the superior planets, is beyond, while in the inferior planets it is within the solar orbit. The description certainly agrees with the supposition that these planets revolve about the sun, and appears to have been expressly framed in opposition to the idea that the earth is the centre of their motion. But the hypothesis which we infer from the language of Pliny is more explicitly announced by Vitruvius [a], who is supposed to have lived in the time of Augustus or, as some think, of Vespasian; and, as the description of the Universe given by this engineer contains, concerning the attractive principle, a curious notion which, probably, was then generally admitted among philosophers, it may not be improper to introduce that description in this place.

The earth, he says, is placed in the centre, and the heavens with the twelve signs revolve about it on the cardinal, or polar axis. Mercury and Venus are the planets nearest to the rays of the sun, and move round the latter as a centre, appearing sometimes progressive, sometimes retrograde and, occasionally, stationary among the signs. "*Mercurii autem et Veneris stellæ circum solis radios, solem ipsum, uti centrum, itineribus coronantes, regressus retrorsum et retardationes faciunt. Etiam stationibus, propter eam circinationem, morantur in spatiis signorum.*" He describes Venus as, alternately, a morning and an evening star, and observes that she does not remain an equal number of days in each sign; but after being delayed in some, she escapes from the impediment, (which he afterwards considers as caused by the sun's rays,) and quickly passes through the rest of the orbit. He states, agreeably to the notion of Aristotle, that all the planets move with equal velocities, and that, on account of their different distances from the earth, they accomplish their revolutions about it in different times, which he illustrates, and the same idea is expressed by Cleomedes [b], by supposing seven ants to be placed in as many circular grooves cut in the plane of a potter's wheel, at different distances from the centre, and to

[a] De Architectura, Lib. IX. cap. 4. [b] De Contemplatione, Lib. I. cap. 3.

be made to move with equal velocities in one direction while the wheel itself revolves in the opposite, he compares this motion of the wheel to the diurnal motion of the heavens and, therefore, the whole illustration would seem to be formed from the old hypothesis of concentric spheres, but it is probable that nothing more was meant than to prove, in a manner which should be intelligible to common minds, that the observed periodical revolutions of the planets were compatible with the opinion of their equal movements; and that no attention was paid to the real orbits. He makes the durations of the revolutions of the superior planets nearly the same as those assigned in the modern astronomy to the sidereal years of these planets; that of Mercury is stated at 360 days which, probably, are intended to express the time of a mean revolution, being nearly the same as that of the sun; but the revolution of Venus is said to be accomplished in 485 days, and, if this is not a mistake, we can only imagine it to refer to the time which may have been observed to elapse between the greatest elongation of the planet on the western side, and that on the eastern side of the sun, which is known to be about 440 days.

Some persons, he says, are of opinion that the stationary and retrograde appearances of the superior planets are caused by the greatness of their distance from the sun, at the times when those phenomena occur; which rendering his light too faint, their motion is retarded by the obscurity, but he asserts that he is of a different opinion; giving, as a reason, that the sun's rays fill all the heavens and, therefore, must always enlighten the divine planets. He thinks those appearances may be caused by the action of heat which, he says, attracts all things to itself; and, to explain his meaning, he observes that the sun extends his rays in the form of an equilateral triangle, and that these attract or accelerate the bodies which follow him while they retard those which precede him, drawing them back, as it were, towards him. It is difficult to conceive what is to be understood by the solar rays being extended in the form of a triangle but, as he observes also, that if the rays from the sun were bounded by a circle, or sphere, the bodies nearest the sun would be burned up, it seems that he supposed the matter of light or heat, without diminishing

in density, to extend itself every way as it recedes from the sun in the same manner as the breadth of a triangle increases from one of the angles to the opposite side; the other expression appearing to imply an opinion that, if the light or heat diminished in density as it receded from the centre, which would be the case if it issued from the sun in right lines like the radii of a circle, the heat near the sun must be so much greater than we find it to be in the region of the earth, that the moon and inferior planets would be destroyed.

In those times the physical principle by which the parts of the universe are connected together must have been very faintly apprehended; for though many passages in ancient authors seem to imply a knowledge of the existence of an attractive quality in nature, like that which Vitruvius supposes to reside in the solar light or heat, and daily observation must have shewn that a heavy body, if unsupported, falls to the earth; yet so little were the ancients able to discern the consequences which must result from such a tendency that, as far as we can discover, they never suspected the power by which all bodies near the earth descend towards its surface to be the cause which renders their rise from that surface impossible without the application of some superior force. This we infer from the language of Pliny, in answer to the question, (which seems, then, to have been frequently proposed,) whether or not there were antipodes to the inhabitants of our hemisphere? and if so, why they do not fall from the earth? He observes, justly, that the latter question may as properly be made concerning ourselves by the inhabitants of the other hemisphere, but his reply is nothing more than an assertion that such a fall would be contrary to Nature, since she has refused a place to which terrestrial bodies may tend in that direction. The imperfection of the sciences was not, however, unfelt by many of the learned among the ancients; nor did it escape the penetration of one who most justly deserved the name of a philosopher, that they would, with the progress of time, receive those improvements which have actually taken place: Seneca, contemplating the state of astronomy, observes [a] that it was only since fifteen hundred years before his time, the Greeks had given

[a] Nat. Quæst. Lib. VII. cap. 25.

names to the stars, and that there were still many nations who only knew the heavens by sight, but, with a prophetic spirit, he says, "the time will come when posterity will be surprised that we could be ignorant of things the knowledge of which might be so easily acquired, and some one will at length arise who shall teach men the paths of the comets, their magnitude and number, and why they deviate so far from the routes of the planets. How many things" he adds, "are beyond the reach of human intelligence; and how small is the part of the universe which is accessible to our knowledge; even the Deity himself is no better known to us." Let it be observed here, that the fifteen hundred years mentioned above, would carry us back to a period more remote than the origin of the Greek astronomy; and it is probable that Seneca confounds the science of the Greeks with that of the Egyptians and Chaldeans.

CHAPTER XIV.

WORKS OF THE ARABIAN ASTRONOMERS.

Decline of Astronomy after the destruction of the Roman Empire.—The Arabians adopt the hypotheses of Hipparchus and Ptolemy.—Their improvements in pure mathematics.—Destruction of the Alexandrian library.—Measurement of an arc of the terrestrial meridian in Syria.—The hypothesis of a libration of the equinoctial points supposed to have been conceived in the age of Ptolemy.—The opinion adopted by the Arabians.—The hypothesis of material spheres adopted by the same people.—Manner of representing the effects of the supposed libration.—Determination of the obliquity of the ecliptic by Albategnius.—The length of the year and the elements of the solar orbit determined.—The elements of the lunar orbit adopted from Ptolemy.—Opinions concerning the distances of the planets.—Researches of Ibn Jounis.—Values assigned by the Arabians to the general precession.—Astronomical tables computed by the same people.—The correction for refraction introduced.—Observatories established at Maragah and Samarcand.

THE science which we have seen glimmering through the obscurity enveloping the ancient history of the Egyptian and Assyrian empires, and shining with a steady lustre over the territories subject to Grecian influence, was marked in its progress by just such steps as might be expected to be taken by an intelligent and industrious people, who persevered in their application to the subject till they had brought it to the highest degree of perfection which their means permitted; and it is highly probable that, had the political existence of the Grecian states been extended to a later period, the moderns would have been anticipated in the discovery of that law which has enabled them to unfold all the mechanism of the universe. But the iron hand of Roman despotism crushed the intellectual energies of the people, and annihilated the sciences both of Greece and Egypt: then, instead of a nation ennobled by the culture of a sublime philosophy, and adorned with the elegant arts, history reveals to us a people of soldiers, originally occupying only a narrow district of Italy, but, subsequently, becoming the conquerors of the most powerful nations of antiquity and rulers of that vast portion of

the earth which extends from the Atlantic to the Indian Ocean; who, in ignorance of that which constitutes true glory, sought theirs only in warlike achievements; or rather, who, in accordance with the precepts of the poet, left to others the care of explaining the form of the heavens and the courses of the stars, and devoted the energies of their minds to the arts of subjugation and government[a]. During the existence of a nation influenced by such precepts it was impossible that astronomy or the other sciences should flourish, and the destruction of the giant empire was followed by a long night of barbarism and ignorance. This continued till the ninth century of the Christian era, when the successors of Mohammed had carried their arms and their religion over all those provinces of Asia and Africa which, during so many ages, had been ruled by the sovereigns of the "eternal city;" and till a new race arose in the west, which, reviving the smothered fires of ancient learning, produced a flame whose steady brilliancy seems destined to enlighten every region of the earth.

But to what can be ascribed this change, which caused so dark a veil to overspread the sun of ancient science, literature, and art, in countries where these had previously been so highly cultivated? The only plausible answer to this question is, that while the empire of Rome subsisted and held those countries in subjection, that portion of the revenues of the states which should have been consecrated to the support of the public seminaries was expended in foreign wars, and that, among the rich and powerful, a relish for merely sensual luxuries had superseded the taste for pleasures of an intellectual nature: when learning ceases to be patronized by a government, or when it is no longer esteemed a qualification for rank in society, it soon ceases to be cultivated; and the painful application of the mind which is necessary to attain proficiency in it is too often gladly dispensed with by persons whose interest it does not immediately promote.

Before the invention of printing, books were rare and costly, therefore not generally diffused, and it must have been in the power of those persons only who were in possession of considerable wealth to place themselves under the tuition of some philosopher

[a] Æneidos, Lib VI ver. 850.

who, perhaps, resided in a distant country; hence the number of students could never have been considerable in the ancient world, and this number would naturally be diminished when the stimulus to exertion was withdrawn. It is certain, also, that an ambitious priesthood, from a love of the power which superior science has always conferred on those who possess it, withheld from the laity the instruction it was its duty to communicate, in order to preserve a monopoly of learning within its own establishments; and, as might be expected from such policy, it happened that, in proportion as knowledge declined among the people, it declined also among the clergy till, at length, all were enveloped in one common cloud of ignorance and superstition.

The immediate successors of Ptolemy appear to have been too well satisfied with the works of that illustrious astronomer to attempt any alteration in the theory he had so extensively developed, and ages undistinguished by any originality of conception or brilliancy of talent, succeeded the publication of the *Almagest*. The second Theon, Pappus, and Simplicius are justly celebrated as commentators of Ptolemy, Aristarchus, and Aristotle; but the other persons who held the chair of philosophy in the east, from the second to the ninth century, are chiefly known as compilers of mathematical elements, in which occur only some occasional notices of astronomy: the low state of the science within this period may be concluded from the language of Isidorus of Seville, who, in the seventh century, and in a work intended for the learned, gravely states that the rising sun is seen at the same moment in Britain and India; that the stars are sustained and guided by angels, and that the universe turns on a material axis which is prevented from taking fire, in consequence of the friction, by water descending on it from heaven.

The Syntaxis of Ptolemy still remained the text book of the schools, and the Arabians, who rekindled the science, did it from the lamp which had been burning, though with continually declining lustre, in the Institution of Alexandria; but it is not to be expected that, during the short period in which the Khalifs were able to afford patronage to the learned, the foundation of astronomy should be renewed; in fact the hypothesis concerning

the system of the universe, which had been received by Hipparchus and Ptolemy from the inventor, appearing to the Arabians conformable to reason and venerable from its antiquity, was by them unhesitatingly adopted; and their energies were simply directed to the improvement of the means of making observations, and of the rules by which the occurrence of phenomena were computed: these were, indeed, objects of importance, since the one contributed to the establishment of correct data, and the other, to diminish the labours of succeeding mathematicians, but they are not to be compared with the science which teaches the deduction of the celestial phenomena from the general laws of nature.

Trigonometry is especially indebted to the Arabians for the introduction of two new functions by which its formulæ are considerably simplified, these are the *sines* and *tangents* of circular arcs; the former was substituted for the *chords* which had been invented by Hipparchus and used ever since his time, the others, which were at first called shadows, seem to have been suggested by the practice of making observations on the sun, with the gnomon, for the length of the shadow cast by a pillar is evidently equal to the tangent of the zenith distance of the celestial body, supposed to be reckoned on an arc of a circle whose radius is equal to the height of the pillar. These functions appear to have been first used in trigonometrical operations by Albategnius, who lived about the year 879 of the Christian era; and if, as is asserted by Lucas di Borgo, who first, in Europe, published a treatise on algebra, that art was discovered by the Arabians, it must be acknowledged that these people have conferred upon the sciences an obligation of the highest order in bequeathing to succeeding mathematicians the most powerful instrument by which physical propositions, and particularly those relating to astronomy, can be investigated. The honour of inventing the numeral characters, and the decimal scale of values at present almost universally employed, by which the processes of computation have been so much facilitated when compared with those rendered necessary by the Greek notation, may be contested between the Arabians and the Hindus, yet the

former people have an indubitable claim to our gratitude since they were the means of introducing that important algorithm to the learned of Europe.

A great merit of the Mohammedan philosophers consists in having availed themselves of the opportunities afforded by the fine climate of Egypt and Syria to make numerous and, for that age, accurate observations on the sun and fixed stars, by which the apparent movements of those celestial bodies, became much more perfectly known than before; it does not appear, however, that they invented any new instruments for this purpose, and it is rather probable that they employed only such as are described by Ptolemy, but, perhaps, made of larger size and more correctly, as well as more minutely, graduated; and as we read of several persons who bore the designation of Alasterlabi, or makers of astrolabes, it is probable that the extent of the demand for such instruments permitted individuals to apply themselves particularly to their construction. Albategnius, speaking of the instrument which he used in his observations for finding the zenith distances of celestial bodies, says[a] it was furnished with a very long alidade, whose nature and use, he adds, is explained in the Almagest; and it appears to have been graduated in minutes of a degree: a similar instrument was subsequently constructed for the observatory at Maragah, having an alidade $5\frac{1}{4}$ cubits long; and it is evident that both must have resembled the parallactic rods mentioned by Ptolemy. The Arabian astronomer, Geber, also, made use of an armillary instrument which was capable of turning on its supports, so that the principal circle could be placed at pleasure in the plane of the meridian, the equator, or the ecliptic, and thus there might be obtained the meridional zenith distances, the right ascensions and declinations, or the longitudes and latitudes of celestial bodies. The circle seems to have been about four feet in diameter, and mention is made of an auxiliary arc, equal to a quadrant, whose radius was of greater length than that of the circle and which, being still more minutely graduated, gave, with superior correctness, the values of the angles taken by the armilla itself.

The commencement of the Arabian empire was marked by an

[a] De Scientia Stellarum, cap 4

event which seemed at first to threaten the total extinction, rather than promise the advancement of literature and science; we mean the destruction of the splendid library formed by the munificence of the Egyptian sovereigns, at Alexandria. The fanaticism which dictated the order for consuming that immense collection of the treasures of ancient learning, certainly does not seem consistent with the liberality subsequently displayed in the efforts made to repair the loss by the acquisition of every valuable work that could be procured; nor could it have been foreseen that a people who considered all necessary erudition to be contained in the koran should become the promoters of that which originated among, and was cultivated by the idolators of Asia and Europe. Yet such was the fact: the charms of "sacred numbers" which had, from all antiquity, been felt in Arabia, probably led, after the rage of conquest was satisfied, to the study of the poets and, subsequently, of the moralists and historians of the West; and the worship of the heavenly host, no less ancient, nor less generally diffused among the Arabian tribes, as probably gave an interest to the astronomical works of the Greeks, the study of which necessarily led to the practice of diligently observing the stars, and supplied a motive for the cultivation of pure mathematics. Thus, as the eloquent Bailly observes[a], like children who destroy the things they possess and then weep over their loss, the Arabs came to seek the light of knowledge at Alexandria, where they had endeavoured to extinguish it; and removed the ashes which remained, that they might collect what the fire and their barbarism had spared.

The determination of the magnitude of the earth we inhabit seems to have been one of the first objects attempted by the Arabians; and Al-Maimon, the son of the famous Aaron-Al-Raschid, who was seated on the throne of Bagdad in the year 814 of our era, appointed the best mathematicians of his age and country to measure the length of a degree of the terrestrial meridian in order, as it is expressly stated, to verify the value obtained by Eratosthenes and Ptolemy. We learn from the translated manuscript of Ibn-Jounis, an astronomer who lived about the year 1000, that these mathematicians were divided

[a] Hist. de l' Astronomie Moderne, Liv. VI.

into two parties; that one party by stretching cords 50 cubits long from south to north in succession, between Waset and Tadmor, measured in the direction of the meridian a certain space which they made equal to 200,500 cubits in length, and whose extremities differed in latitude by one degree; and that the other party measured, in the plain of Singiar, also a degree of latitude which they found to be nearly of the same length, the difference between them being about $\frac{1}{76}$ of the terrestrial arc[a]. The length above assigned to the degree of the meridian was stated by the persons who performed the operation to be the same as that given by Ptolemy, its precise value would be of small importance at present, even if it could be ascertained, on account of the probable inaccuracies of the admeasurement; but the greatest uncertainty prevails respecting the length of the cubit here employed; for some of the Arabian geographers make it equal to 6 palms, that is, to about 2 English feet, while the Jewish astronomer Abraham asserts that the mathematicians of Al Maimon used a cubit whose length was 4 palms, or about 16 inches, and according as we adopt the first or second of these values, the length of the degree would be about 76, or 51 English miles respectively. Alfraganus relates[b] that "the learned men who, in the time of Al Maimon, measured the length of a degree made it equal to $56\frac{2}{3}$ miles, each containing 4000 *royal cubits*:" and, if we take the mean length of a degree of the meridian to be 69 English miles, it will be found that the royal cubit must have been equal to $19\frac{1}{3}$ inches.

It seems probable that some of the more ancient astronomers occasionally reckoned the longitudes of the stars not from the true equinoctial point, but from some fixed star whose ecliptic place was considered as the origin of the longitudes, just as some terrestrial meridian arbitrarily chosen is now used for the origin of the longitudes of places on the earth; and the registers of the ancient observations not being always accompanied by a designation of the assumed origin of the celestial longitudes, it has happened that, in comparing such observations with others made on the same stars when the longitudes were really reckoned from

[a] Delambre, Astronomie du Moyen Age, pages 78 and 97.

[b] Elementa Astronomia, cap 8.

the equinox, a mistaken notion arose concerning the position of the vernal equinox; which was, thence, supposed to be subject to a variability of movement independent of the precession, and to advance and retrograde alternately upon the ecliptic, within certain limits, about its mean place The idea of this movement of trepidation, as it was called, appears to have been entertained in or before the time of Ptolemy; though as this astronomer does not notice such a motion, in his works, it is evident that he must have considered it as unsupported by any observations worthy of confidence. Theon, his commentator, alleges that the opinion was maintained by the ancient astronomers, probably meaning the professors of the art of astrology, who appear always to have held notions which formed no part of the creed of men of real science; and he adds that the extent of the motion was said to be 8 degrees on each side of the mean place: he makes the rate of motion equal to one degree in 80 years, so that the equinoctial and solsticial points must have been supposed to come, at the end of every period of 1280 years, to those points of the ecliptic which they would have arrived at by the general precession.

The particular data on which the supposed fact of the trepidation and its amount were founded are quite unknown, but, possibly, there might have been then in existence records of many observations similar to those quoted by Ricius[a] from the Jessod holam [*De fundamento mundi*], a work composed in the beginning of the fourteenth century by the Jewish writer Isaac; the observations we allude to, which are said to have been made by a certain Hermes 1985 years before the time of Ptolemy[b], shew the longitudes of the stars Regulus and Cor Hydræ, and if real, those longitudes would appear, at that time, to have been greater by 7 degrees than the longitudes assigned by the latter astronomer to the same stars, whereas, by the effect of precession, they ought to have been less by about 28 degrees, it, therefore, appeared that, within the above period, the equinoctial point had moved according to the order of the signs, or in a direction contrary to that which constitutes the precession. But the age in which this Hermes is said to have lived is believed to be fictitious

[a] De motu octavæ sphæræ. [b] Ricius ut suprà.

and, as the account of the observations simply states, that one of the above mentioned stars was in a certain degree of Leo, it will be very natural to suppose with Ricius, and the supposition destroys the hypothesis of trepidation, that the star was by the ancient observer whoever he may be, referred to the constellation Leo, which is fixed in the heavens, and not to the fifth sign of the ecliptic, reckoned from the equinoctial point, which is moveable. Bailly, on the other hand, contends [a] that the longitude of the said star is to be referred to the equinoctial point, but he conceives that Hermes, or the observer who bears his name, made use of the Hindu zodiac whose origin, at the above epoch, he shews to have been situated 35 degrees from the equinox, according to the order of the signs; and, consequently, the place of a star in that zodiac would, then, appear to be 7 degrees more advanced in longitude than its place, in the time of Ptolemy, according to the Greek zodiac: but the absence of any direct evidence to prove that observations of this nature were made by any person using the Hindu zodiac, at so early a period as 1985 years before the time of Ptolemy, is a good reason for preferring the former supposition.

In the Jessod holam above quoted from Ricius [b], Hermes is stated to have recommended that "*the philosopher should carefully consider the ship hanging in the air, which during four hundred years ascends, and during an equal number of years, descends*" The ship here mentioned is, by Rabbi Isaac, thought to designate one of the equinoctial points; and the ascent and descent, to designate the motion of trepidation; but it is evident that, from expressions acknowledged by the relator to be obscure and of uncertain meaning, and ascribed to a person whose existence is doubtful, nothing can result in favour of the opinion that the hypothesis of trepidation was known in the times of the ancient Babylonians and Egyptians.

If any dependance may be placed on a statement made by the same Isaac, that about 750 years before his time (consequently about A. D. 560) the head of the constellation, and the commencement of the sign Aries, were together, or in conjunction, we shall be enabled to form an opinion in what particular part

[a] Astronomie Indienne, discours préliminaire. [b] De motu octavæ sphæræ.

of the heavens the origin of the Arabian zodiac was situated; for the place of the vernal equinox in 560, being computed from the known value of the precession, will be found nearly coincident in longitude with the star ζ Piscium, or about 13 degrees westward from a circle of longitude passing through γ Arietis, near which last passes the present boundary line between these two constellations. As there is no remarkable star near the said place of the equinox by which the head, or beginning of the constellation Aries could have been distinguished, it seems unlikely that such a spot in the heavens should have been chosen for the commencement of the twelve zodiacal constellations; we may, therefore, reasonably suppose that the divisions whose origin is referred to by the Jewish writer, were merely the twenty-eight lunar mansions used by some of the Arabian astronomers [a], and in his time, generally, by the professors of astrology. We shall see, hereafter, that the origin of the twenty-eight asterisms into which the Hindu zodiac was divided was, also, situated near the star ζ Piscium above mentioned.

The idea of an alternately direct and retrograde motion of the equinoctial points, having by some means found a place among the other conceptions of that age, concerning the systems of the heavenly bodies, was adopted by the Arabians, who made an effort to exhibit it by an additional movement given to the sphere with which, according to Eudoxus and Calippus, the fixed stars were connected. This modification is developed, in a manuscript work on the motion of the eighth sphere, by Thebith-ben-Korah [b], who probably lived about the year 1000 of the Christian Era, but it is right to observe, and it is asserted by Alpetragius, an Arabian astronomer of the twelfth century, that the hypothesis itself was not universally admitted among that people: Albategnius [c] argues against it on the ground that, during certain times, the movement of trepidation is in a contrary direction to that of the general precession, and, agreeably to the laws then laid down for the motions of the celestial spheres, two contrary movements cannot exist at the same time in the

[a] Hyde on the Tables of Ulugh Bey.

[b] Delambre, Astronomie du Moyen Age, p. 73.

[c] De Scientia Stellarum, cap. 52.

same body or point; and Thebith, in a letter to the physician of the Khalif Motavekel, expresses a doubt of its reality, though it is probable that, at a subsequent time, he admitted it with confidence: even among those who received the hypothesis, a difference of opinion prevailed respecting its amount; Albategnius[a] agrees nearly with Theon in the value assigned both to the rate, and to the extent of the movement; but, according to Thebith, who has given a table of the equation of the equinoctial points, dependent on the supposed trepidation, the greatest extent of the deviations, in latitude, from the fixed ecliptic was 4° 18′ 43″, and, in longitude, 10° 45′ from the mean place; and the restitution was supposed to take place in $4171\frac{1}{2}$ years.

From whatever cause it may have originated, it is found that the Hindus, in an age perhaps somewhat earlier than that of Albategnius or Thebith, entertained opinions similar to those ascribed to the latter, on the subject of the movements of the equinoctial points: and the following account of them, from an interesting essay by Mr. Colebrook *on the notions of the Hindu Astronomers*[b], will probably be considered as strengthening the idea, that the sciences of Arabia and India were then closely connected together, it being not likely that the people of those countries should, independently of each other, have formed an hypothesis which is now well known to have no foundation in nature.

Mr. Colebrook states that Bhascara, in his description of an armillary sphere, and also in a quotation from a more ancient astronomer, Munjala, mentions the retrograde motion of the equinoctial points; but he asserts that this is at variance with the text of the Sourya Siddhanta, and of several other works, in all of which the revolution, as it is called, of the equinoctial points is made to consist in a libration of those points, within the limits of 27 degrees eastward, and as many westward of Aries, (probably their mean place), and of these librations it is added that 600 are performed in one yuga [=432000 years], or 600000 in a Calpa. The same doctrine, he observes, was maintained by the very ancient astronomer Aryabhatta, according to a quotation from the works of the latter by Muniswara,

[a] Ut supra. [b] Asiatic Researches, Vol. XII.

one of Bhascari's commentators, only the number of librations in a Calpa is made equal to 578159 instead of 600000, and the limit of each is said to be 24, instead of 27 degrees. It may, therefore, safely be inferred that the opinion of a libration, or trepidation, of the equinoctial points is of considerable antiquity in India, but it will be in vain to attempt a reconciliation of the values assigned by the Arabians and Hindus to the period in which a libration is performed, or to the extent of a libration on each side of the mean equinox; partly on account of our ignorance concerning the precise values of the Hindu yugas and calpas, which, indeed, are of variable duration, and concerning the manner in which this people understood the libration to be produced: we shall see presently that the Arabian astronomers supposed the plane of the ecliptic to be moveable on a small circle, or sphere, whose centre is in the mean place of the equinoctial point; and it is evident that a small difference in the magnitude of this circle would make a considerable variation in the extent of the interval between the mean and true intersection of the ecliptic and equator when that interval is a maximum.

In the astronomy of the Arabians, some confusion prevailed concerning the constitution of the Universe, and there seems to have been one theory for the learned, and another for the vulgar, or, perhaps, for the astrologers; for though in their scientific investigations, this people adhered to the ideas of Ptolemy, and considered the planets to revolve on the circumferences of epicycles, yet we find their writers proposing to return to the material and concentric spheres of Aristotle, and alleging, as a reason for so doing, the complexity of the eccentric spheres and epicycles which enter into the planetary theory of the Astronomer of Alexandria. Now if, as is most probable, Ptolemy or his immediate disciples considered the planets to perform their revolutions in immaterial orbits, it must be admitted that the system they professed to follow was, in this respect, advantageous, because it left a way open for the future improvement of Astronomy, when, by the sagacity of some profound enquirer into the physical laws which govern the universe, the principle should be discovered by which the sun and planets preserve

their relative distances from each other; whilst the Arabians, by the adoption of the clumsy machinery constituting the older hypothesis, caused a retrograde movement, in the science, which was not recovered till the days of Copernicus and Kepler.

Thebith, like the ancient Greeks, imagined that to each planet belonged a system of spheres of whose movements that of the planet was compounded, beyond these he supposed there was situated what was called the eighth sphere, which contained the fixed stars, and which, according to Ptolemy, performed a revolution about the axis of the ecliptic, in direct order, in 36000 years, producing the movement of precession at the rate of one degree in one hundred years; and on the exterior of this he placed a ninth sphere, called the Primum Mobile, or the sphere of spheres, whose movement from east to west, caused the observed diurnal revolution of the heavenly bodies. On both these spheres were conceived to be described great circles representing the ecliptic and equator, and between the spheres were placed two others, diametrically opposite to each other, which revolved on an axis coincident with a line drawn through the earth and the equinoctial points on the ninth sphere, while this axis was carried round the heavens by the general precession. The radii of these spheres were supposed to subtend at the earth angles of 4° 18′ 43″, and the equinoctial points of the eighth sphere were made to revolve upon their surfaces, so that the ecliptic and equator of this sphere appeared to rise and fall, to advance and retrograde, alternately, with respect to those of the ninth sphere, thus producing the variations of latitude and longitude, which were thought to be observed in the fixed stars: the values of these trepidations at any given times, were made proportional to the sine of the arc, on the surface of either small sphere, which measures the angular distance of the moveable equinoctial point from the plane of the fixed ecliptic; but the manner in which these movements of the equinoctial points were supposed to take place, will be better understood from the following explanation.

Let ÆBQD [Plate III. fig. 4] be the position of the mean equator, whose pole is Π, Æ and Q being the mean places of the

equinoctial points, and let a b c d, l e f g be circles formed by pl
perpendicular to the mean equator, cutting, centrally, the
spheres above mentioned; the equinoctial points of the ei
sphere describe the circumferences of these circles, and w
the vernal equinox is at a, let ♈ a ♎ be the position of the m
able ecliptic, p its pole and ♈ and ♎ the positions of the m
able equinoxes, on the equator of the ninth sphere. Then, w
a describes the semicircle a b c, the point p will describ
half p π p′ of the looped curve about π and the point ♈ will
trograde through the arc ♈ ♈′, so that when the equinox of
eighth sphere is at c, the ecliptic will take the position ♈′
again while this equinox is moving from c, through d, to a
pole of the ecliptic will describe the other half p′ π p of
looped curve, and the equinox of the ninth sphere will r
from ♈′ to ♈. During the revolution of the equinoxes on
eighth sphere upon the circumferences of the circles a b c d,
the pole of the equator on that sphere, will vibrate contin
in the arc P P′ which is equal to the arc a c. The arc of a
circle between Π and p, or between Π and p′, which mea
the angle at ♈ or ♈′ will express the greatest, and the arc
will express the least obliquity of the ecliptic; the former
by Thebith, made equal to 23° 51′ 20″ and the latter, to 2
40″; whence, Π π p being a right angle, the arc of a great
between π and p must have been equal to 3° 56′ 56″;
because this arc is to the corresponding arc between Π an
or between Æ and a, as the cosine of Π π to radius, it fo
that the radii of the circles or spheres of trepidation w
subtend at the earth angles of 4° 18′ 43″, as above. Th
♈ Æ, which is half the trepidation in longitude will, from
data, be 10° 42′ 50″, and Thebith makes it equal to 10°
but this element is, evidently, a result of computation, fo
on the differences, in the obliquity of the ecliptic, arising
errors of observation; and the situations of the equin
points, according to determinations made from the sup
law of their movement, could never have been compared
those resulting from the observed longitudes of stars w
demonstrating the inconsistency of the hypothesis.

Averroes of Cordoba is said, by Copernicus, to have pro

in order to account for the movement of the planets in latitude, that the sphere belonging to each should have a libratory motion from north to south, which, being combined with the diurnal motion produced by one of the other spheres connected with the same planet, would cause the latter, apparently, to describe, within certain limits of latitude, a spiral movement about the earth. There is no account of the manner in which this libration was to be effected, but it is easy to conceive that it might be produced in a manner similar to the movement of trepidation above explained, by causing the sphere of the planet to revolve so that a certain point on its surface may describe the circumference of a small circle about the pole of the ecliptic, while the planet itself is situated at the extremity of a diameter at right angles to that drawn through the said point and the centre of the sphere; for then, the planet will vibrate, in an arc of a great circle perpendicular to the ecliptic, about the place of its node as, in fig. 4, the point P vibrates on each side of Π.

Albategnius, whom we have before mentioned, was an Arabian prince, residing at Aracte in Syria, about the end of the ninth century of our era, and was apparently, a diligent observer of the heavens. In his treatise *De Scientia Stellarum* [a] he relates, after stating the result of Ptolemy's observations for finding the obliquity of the ecliptic, that he himself, having carefully verified the positions of his instruments, had repeatedly found the sun's meridional zenith distance, on the days of the summer and winter solstice, to be 12° 26′ and 59° 36′, respectively; whence the distance between the tropics appeared to be 47° 10′, and the obliquity of the ecliptic, 23° 35′; and this, being corrected for refraction and the sun's parallax, becomes 23° 35′ 41″: we learn also, from the relation given by Ibn Jounis, that three astronomers who had observed the obliquity at Bagdad, in the year 200, of Yesdijird [832 of our era] made it equal to 23° 33′ 52″: the near agreement of these results with each other affords some evidence that they do not differ much from the truth, and, if we compare them with the obliquity found by Ptolemy or Hipparchus, they present an additional argument in favour of the progressive diminution of that element

[a] Cap. 4.

The observations of Albategnius show that Aracte must have been situated in about 36 degrees, of north latitude; its longitude is said to have been 10 degrees east of Alexandria.

Comparing the time of an equinox observed by himself with one of those observed by Ptolemy, Albategnius[a] finds the interval to be 743 years 185.75 days, whereas, had the year consisted of $365\frac{1}{4}$ days, that interval would have been 743 years 178.73 days; the difference between these, being divided by 743, gives 0.00944 days for the excess of $365\frac{1}{4}$ days above the true tropical year, which, therefore, he makes equal to 365.24056 days, a quantity nearer the truth than the length assigned by Ptolemy, but, still, too small. By the observed inequality in the length of the summer and winter half years, and by a method similar to that of Hipparchus, he finds the longitude of the solar apogeum to be $2^s\ 22^\circ\ 17'$, the maximum equation of the centre to be $1^\circ\ 59'\ 10''$, and the double eccentricity, 0.03465, the mean distance of the sun from the earth being unity: these quantities, though rather too great, also approach nearer to the truth than those found by Ptolemy. If Albategnius compared the place he had found for the sun's apogeum with that assigned to it by Ptolemy, [$2^s\ 5^\circ\ 30'$] he must have discovered the progressive motion of that point, and dividing $16^\circ\ 47'$, the difference of the two places, by 740, the number of years in the interval, it would have been found equal to abont 80 seconds yearly; this includes the movement caused by the precession, and exceeds the truth by about 17 seconds, which may be easily supposed to have arisen from the inaccuracy of the observations; but there is no certainty that, in this age, such comparison was made, or that the Arabians had then any fixed ideas concerning the proper movements of the apsides or even of the nodes of the planetary orbits; for Alfraganus, who also lived in the ninth century, in speaking of the general precession[b] ascribes it to a motion of the sphere of the fixed stars which (agreeably to the determination of Ptolemy) he says, is at the rate of one degree in 100 years, and adds that "the seven planetary spheres are turned with the same motion, so that the apsides and nodes revolve in consequentia, and de-

[a] De Scientia Stellarum, cap. 17. [b] Elementa Astron., cap. 13.

scribe the circumference of the zodiac in 36000 years": evidently thus excluding the opinion of a proper motion in either of those points. Arzachel, who lived in the beginning of the twelfth century, from observations still more erroneous than those of Albategnius, thought he perceived in the apogeum of the solar orbit, a retrograde movement equal to 4 degrees in 193 years, and, combining this with the progressive motion found from the observations of the last mentioned astronomer, he supposed the apogeum to have a libratory movement which, with an observed variation in the eccentricity, he represented by making the centre of the sun's orbit revolve on the circumference of a small circle, while the line of the apsides moved always parallel to itself.

Albategnius seems, as Delambre observes, to have made no change in the values assigned by Ptolemy to the elements of the lunar orbit except as far as the motion of the sun is concerned, which, on account of the diminished value of the year, he makes more rapid than it had been supposed by the last mentioned astronomer. His observations of eclipses enable us, by comparison with those made in more ancient and modern times, to verify the mean motions of the moon; and from two of these, which he observed in the years 883 and 901 of our era, when the sun was in apogeo, and when, in both, the moon had nearly the same mean longitude and latitude, he finds a difference in the true latitudes of the moon equal to 3′ 50″. hence he calculates the visible diameter of the moon, and assuming, with Ptolemy, the diameter of the earth's shadow in the region of the moon to be $2\frac{3}{5}$ of the diameter of that luminary, he finds the latter, in apogeo and perigeo, to be 29′ 30″ and 38′ 30″ respectively, and, subsequently, the sun's mean distance to be 1108 semidiameters of the earth.

We have before observed that the ancients could have had no correct notions of the distances of the planets from the earth; and since Ptolemy observes that their parallaxes, probably meaning those of the superior planets, were insensible, he must have thought them incalculably remote; but we learn from Albategnius that the philosophers before his time, and subsequently to that of Ptolemy, had assigned limits to the real or

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imaginary spheres of the wandering stars. He asserts[a] that about the earth, or the centre of the universe, and ascending from thence, there exist the several regions of earth, water, air, and fire, the last of which extends as high as $18\frac{1}{2}$ semi-diameters of the earth. In all the space beyond this there exists, he observes, an ethereal matter, or fifth essence, which he denominates *Alacir*, not cognisable by human senses, and in which the celestial bodies perform their revolutions. The planetary spheres are said to be in contact with each other, and the thickness of each, equal to the difference between the apogeal and perigeal distances of the planet itself: thus, the distance of the lunar apogeum from the earth being equal to $64\frac{1}{6}$ semi-diameters of the latter, this quantity becomes the least distance of Mercury, or that of his perigeum; and the ratio between the perigeal and apogeal distances of this planet being found (he states) by careful observations to be as 1 to $2\frac{7}{12}$, it will follow that the greatest distance of Mercury, and, consequently, the least distance of Venus, from the earth, is 166 semi-diameters of the latter. The ratio between the least and greatest distances of Venus is said to be as 2 to 13; and hence, the latter, which he makes the same as the least distance of Mars, becomes 1079 semi-diameters. The proportion between the least and greatest distances of Mars is said to be as 1 to 7; therefore the latter is made equal to 7553 semi-diameters: in like manner the distances of Jupiter and Saturn are determined, and the greatest distance of the latter is said to be equal to 18094 semi-diameters of the earth. There is some mistake, however, in the numbers expressing the least and greatest distances of the two last planets; for, if those given in the work of Albategnius are correct, the orbits of those planets must have been supposed to intersect each other: also the least and greatest distances of the sun are said to be 1079 and 1137, so that the sphere of this luminary seems to be part of that of Mars. With respect to the fixed stars, it is said that twelve of them are of the first magnitude, and their distance from the earth is supposed to be equal to 19000 semi-diameters of the latter; evidently intending to shew that those bodies are contained in a sphere whose inte-

[a] De Scientia Stellarum, cap. 50.

rior surface is nearly contiguous to the exterior surface of the sphere of Saturn. Albategnius makes their diameters equal to one twentieth of the diameter of the sun, and this he considers as the greatest body in the universe.

Alfraganus assumes the same hypothesis concerning the arrangement of the planetary spheres as that above described; he also supposes the apogeum of each to be at the same distance from the earth as the perigeum of the next superior planet, and there is not that confusion in the situations of the spheres of the sun and Jupiter which is observed in the account given by the former astronomer; but, except the sphere of the moon, to which he assigns the same magnitude that it has in the system of Albategnius, all the spheres, if the numbers in the text are correctly stated, are rather more extensive, the greatest distance of the sun being 1220 semi-diameters of the earth, and that of Saturn, 20110 semi-diameters [a]. This writer, in the sixteenth chapter of the same work, has given his determinations of the eccentricities of the deferent spheres, and the diameters of the epicycles, which, however, agree, very nearly, with those obtained by Ptolemy, and which we have already mentioned.

These erroneous notions concerning the distances of the planets, besides leading to the opinion that the shadow of the earth should extend beyond the orbit of Mercury, and cause that planet to suffer eclipses like the moon, produced some discrepancies between the theoretical and observed values of the parallaxes; we have said that Ptolemy supposed the parallax of the sun to be 3 minutes; and, according to the above hypothesis, the parallax of Mercury should have been equal to that of the moon, both of which are far from being conformable to observation; in order, therefore, to diminish the errors, Ibn Jounis, at the end of the tenth century, enlarged the sphere of the sun, making his mean distance from the earth equal to 1766 semi-diameters of the latter, and the perigeal distance of Mercury equal to 115 semi-diameters, by which the sun's parallax was reduced to 2 minutes, and the greatest parallax of Mercury, to 30 minutes, but both of these are still much too great, and the maximum parallax of Venus, which, in reality, exceeds that of Mercury, was made equal only

[a] Elementa Astron., cap. 21.

to the minimum parallax of the latter planet. About the middle of the twelfth century Alpetragius, another Arabian astronomer, held the notion that Mercury and Venus shone by their own light[a]; but this idea seems to have arisen from the impossibility of distinguishing them by the naked eye when they come between the sun and the spectator, or of perceiving the crescent form which, if enlightened by the sun, they should assume when nearly in conjunction with that luminary. Averroes, however, in his commentary on the Almagest, states that he saw two dark spots on the sun at times when, by computation, Mercury and Venus were to be in conjunction with him, and though it is probable that these were, merely, extensive displacements of the luminous matter about the nucleus of the sun, yet the opinion that the transits, as they have been since called, of these planets were phenomena resulting from the positions of their orbits is thus proved to have been then entertained; and the fact that the planets are opaque bodies must have been considered as established.

A fragment of a work on the Arabian astronomy, which was composed at the end of the tenth century by Ibn Jounis, whom we have mentioned above, and which has fortunately been preserved in manuscript, was a few years since translated by M. Caussin, and is particularly valuable since it affords the means of making comparisons of the elements of the sun, moon and planets, found by observation, at that time, with those previously and subsequently determined in like manner. The author of the work was a descendant of a noble family, and pursued his researches at Cairo under the patronage of Hakem, the Khaliph of Egypt, to whom he dedicated an improved series of astronomical tables. From several observed equinoxes and solstices he computes the elements of the solar orbit, he fixes the obliquity of the ecliptic, in the year 1000, of our era, at 23° 35′, and determines the equation of the centre to be 1° 59′ 10″; the value of the latter is much nearer to the truth than that assigned to the element by Hipparchus, but, as Delambre observes, it is too great, for the age of Ibn Jounis by 1′ 10″, and is not quite so correct as the value found by Albategnius. He makes the length of the tropical year, from the same observations, equal to 365 24235 days, which does not exceed the truth by above 8 seconds. He

[a] Ricciolus Almag. Nov.

makes the longitude of the solar apogeum equal to $2^s\ 22°\ 1'\ 37''$, which is also nearer the truth than the longitude given by Ptolemy; but, like the last mentioned astronomer, he seems to consider the apogea and nodes of all the planetary orbits to be stationary in the heavens, since he makes the increase of their longitudes equal to the retrogradation of the equinoctial points. He makes few changes in the elements of the lunar orbit, but, as he determines the equation of her centre by means of eclipses, the equation of evection remains as it had been determined by Ptolemy. Besides the elements of the solar and lunar orbits, the Arabian astronomer has given the times of several conjunctions of the planets; occultations of stars by the planets, and a register of several observed longitudes of Regulus, of which, that made in the year 976 of our era, is equal to $4^s\ 15°\ 6'$; and from this, by comparison with the longitude assigned by Ptolemy, 836 years previously, the annual precession would appear to be 54 seconds; but if the comparison be made with the longitude found by Hipparchus, 1142 years previously, the precession would be $48\frac{1}{3}$ seconds, and if, with the longitude assigned to the same star in the year 1820, which is 844 years from the date of the observation made by Ibn Jounis, the annual precession would be found equal to $51\frac{1}{2}$ seconds; and these two last comparisons may be alleged as proofs that the observations, both of Hipparchus and the Arabians, were superior in accuracy to those of Ptolemy. Albategnius had also determined the value of the precession by comparing the longitudes of Regulus and of the northern star between the eyes of Scorpio [β Scorpionis], both of which were observed by Menelaus, or Milleus, in the year 842 of Nabonasser, with the longitudes of the same stars observed by himself in the year 1627 of Nabonasser [A. C. 880]; consequently at an interval of 785 years [a]; and the conclusions to be drawn from the data he has mentioned are that, by the former star, the annual precession in longitude is 68.6 seconds, and by the latter, 54.25 seconds: the difference is very considerable, and proves that there must have been great errors in some of the observations, but Albategnius adheres to the last determination, which, however, is too great by above 4 seconds. The same astronomer adds, that he found no perceptible differ

[a] De Scientia Stellarum, cap. 51.

ences in the latitudes of the stars; and, in fact, the chang[...] their places with respect to the ecliptic are too small [...] been sensible in observations made with such instruments [...] then used.

During the long interval which had elapsed since the [...] Ptolemy, it does not appear that any attempt was made [...] rect the errors in his tables of planetary motion which, [...] years, must have been very perceptible; this was, probably [...] done by the Arabians who, however, could only have empl[...] for this purpose, equations of an empirical nature, being [...] sarily ignorant of the mutual perturbations exercised by [...] moon and planets upon each other, by which so many [...] variations in their movements are produced. The first [...] Arabian tables were, probably, those of Albategnius, whi[...] the places of the sun and moon; they appear to have be[...] posed about the year 879, and to be but an improvement [...] tables of Ptolemy. The most celebrated are those of Ibn [...] which are referred to the year 1000 and, being dedicated [...] Khaliph Hakem, were designated the Hakemite tables; [...] sequently to these, the tables of Toledo were calculated by [...] chel, who lived in Spain about the year 1180 It is highly [...] that, in the times of Hipparchus and Ptolemy, ephe[...] were calculated for the purpose of facilitating the invest[...] of astronomers; but there can be no doubt that the Ar[...] were in the practice of executing such works, since they [...] alluded to in a letter of Thebith, from which it appears that [...] shewed the times of the new, and full moons, and predict[...] occurrences of eclipses. In their tables of the fixed stars [...] no doubt, corrected the places of these celestial bodies fr[...] catalogue of Ptolemy by applying the amount of the pre[...] in the interval, but, as the corrections were made by pers[...] estimated this element too highly, the longitudes they [...] cannot be expected to agree with those found, for that [...] by computing backward, with the data afforded by [...] observations.

On contemplating the works executed by the Arabians [...] cannot hesitate to admit that the modern astronomy is [...] indebted to that ingenious people for the corrections they [...] in almost every one of its elements, which, consider[...]

short duration of their empire, could only have been accomplished by an almost uninterrupted application to the practice of observing the heavens: we have shewn that they had determined the obliquity of the ecliptic, and it is found that the result of their investigations, though affected by their error concerning the sun's parallax, is so far conformable to the theory of gravitation as to indicate the progressive diminution of that element; a like conformity, and a like indication is also perceived in the value they assigned to the equation of the sun's centre The length they found for the tropical year, and their determination of the place of the sun's apogeum are, both, within a few seconds of the truth; and their tables of planetary motions, being compared with those of recent construction, confirm the secular equation of the moon and the great inequalities of Jupiter and Saturn. To all which we may add their many observations of eclipses, and of the conjunctions of planets; their employment of the method of fixing the time at which any phenomenon occurred, by the contemporaneous altitude of the sun, and the very accurate rule for correcting the calendar, by the intercalation of eight bissextile years in every thirty-three current years, proposed by Omar Cheyan about the year 1079 of our era; and the whole will furnish a very interesting picture of the learned labours performed by this remarkable race of men within little more than two centuries: during this brief period their science, as well as their political power, gleamed like a meteor and then, suddenly, vanished from the sight.

The immense size of the instruments used by the Arabians must have given them advantages over the ancient astronomers with respect to the accuracy of the observations; it is said that, in the year 995, the obliquity of the ecliptic was measured with a quadrant whose radius was 15 cubits; and in 992, with an instrument whose radius was equal to 40 cubits, or about 58 feet: but it may be doubted whether, in general, the advantages are proportional to the magnitude of the instruments, from the difficulty which must attend the performance of the requisite adjustments

In this glance at the works of the Arabian astronomers we must not omit to mention that they corrected their observations, at least when made on celestial bodies near the horizon, on ac-

count of the refraction of light in the atmosphere, and this contributed materially to give them a superiority in point of accuracy over those of the Greeks. It is true, that the phenomena of refraction must have been known to Ptolemy, since he speaks of them in his work on Optics, but he does not notice the subject in the Syntaxis where the application of it would have been of great importance; and this has induced an opinion that he had not discovered those phenomena till after the composition of that work · it is evident, therefore, that the observations made by this astronomer, as well as by all those who preceded him, on the apparent places of stars, must be affected by this cause of error. It is worthy of observation also, that some of the phenomena of the refraction of light must have been known before the time of Ptolemy; since Cleomedes[a] makes an allusion to the well-known experiment of rendering visible a ring, or other object, when placed in a vessel, by filling the latter with water: this is the first notice extant concerning the effects of refraction, but it is connected with the erroneous notion, prevalent among the ancients, that in vision, the rays of light proceed from the eye to the object. Alhazen, the author of a treatise on refraction, was the first writer who gave a reason for the apparent magnitude of celestial bodies in the horizon, he ascribes it to a tacit judgment formed by the mind from the idea which, in that situation, is entertained of great distance; and this, he observes, is excited by the number of terrestrial objects then perceived between the celestial bodies and the spectator

The astronomy of the Arabians was, at the decline of the empire of the Khaliphs, and about the time of the revival of learning in Europe, cultivated in the northern part of Persia: from an Arabian MS., the writer of which lived in the thirteenth century, we learn that a grandson of Gengis-khan took into his service Nassir-Edin, an Arabian or Syrian astronomer, by whose direction an observatory was built at Maragah where, from the year 1261, were made a number of celestial observations which the mathematicians of the prince used for correcting the tables of Ptolemy; these new tables were afterwards published and, being dedicated to the Tartarian Prince Ilchan, they, from him, received the denomination of the Ilcanic tables. The observatory itself

[a] De Mundo, Lib. II cap 5.

was a remarkable structure, since it formed a great sun-dial, being crowned with a dome, having an opening through which the rays of the sun passing, indicated the hour of the day and the altitude of the luminary. The instruments used in the observations appear to have been similar to those of Ptolemy and the Arabians; the writer of the MS., in enumerating them, mentions an armillary sphere which was to be employed when the celestial body was not on the meridian, and on whose alidade he proposes that there should be a tube to protect the eyes; probably meaning that it should contain some coloured transparent substance similar to the dark glasses at present employed when viewing the sun. In describing an instrument to measure the diameter of the moon, he says its alidade should carry two plates, of which that next to the eye should have a small aperture pierced in it; the other, a larger, and the latter plate should be moved forward or backward till the full moon exactly filled its aperture, then a scale graduated on the alidade served to determine the value of her diameter

The last circumstance of importance connected with the astronomy of that part of the world is the construction of a magnificent observatory at Samarcand, about the year 1400, by Ulugh Bey, a descendant of Tamerlane: this prince caused the obliquity of the ecliptic to be measured with a gnomon of great dimensions, and a catalogue of stars to be formed, in the preface to this work, it is stated that there are eight stars marked in the catalogue of Ptolemy which could not then be found in the heavens, and among these are mentioned six unformed stars near the southern fish. Bailly observes that these six have not since been marked in any catalogue; whence he thinks it probable that they may have disappeared between the times of Ptolemy and Ulugh Bey, for, since four of them were, according to the former astronomer, of the third magnitude, it is not likely that they would have found a place in his catalogue if they had not then been visible in the heavens. A work on astronomy, composed by order of the Tartarean prince, was, in 1665, translated by Greaves and Hyde: it contains a series of tables which were considered preferable to those of Nassir-Edin, and are admitted by Delambre to be tolerably exact for the age in which they were computed.

CHAPTER XV.

THE ASTRONOMY OF THE ANCIENT HINDUS.

The antiquity of the Hindu astronomy inferred from their tables.—The four Hindu ages supposed to be founded on astronomical periods —Probable source of the eastern fables concerning the renewals of the earth.—Situation of the point at which the Hindu zodiac commences.—Length assigned by the Hindus to the solar year —Epochs of Hindu tables.—Erroneous value assigned by the Hindus to the precession.—Observations on the elements of the Hindu Tables —The planetary system of the Hindus similar to that of the Greeks.—Instrumental observations were made by the Hindus.—Lunar periods known to this people —Probability that the Hindu astronomy is formed by improvements on that of the Chaldeans, Greeks and Arabians.

The great antiquity of the Hindu astronomy has been the subject of much discussion among the learned of Europe; on the one hand, the evidence afforded by the tables brought from the countries on this side of the Ganges leads to an opinion that the science had been cultivated there long before the Noachian deluge is supposed to have taken place, and on the other hand, the entire absence of all notice of these tables and, indeed, of any circumstance connected with the science or history of a period so remote, not only in any Sanscrit writing known to exist, but in any document relating to the learning of the neighbouring countries, Assyria and Persia, where the practice of observing the heavens, in very ancient times, was diligently pursued, and where such works, if then in being, could not have been unknown, gives rise to a well-founded suspicion that the tables may have been fabricated in a later age. We are to add to this, and the fact is highly confirmative of the suspicion, that in the immense interval between the epoch of the tables and the probable origin of the modern astronomy in India, no traces appear that the science was cultivated in that part of the world, where yet it is supposed to have been, previously, brought to a state of great perfection. Even if we admit all that has been alleged concerning the antiquity of astronomy, since every monument of its

existence must have perished when the first philosophers from Europe visited the East, that science was, to them, as though it had never been; it was to be anew discovered, and its gradual rise can only be traced in the few accounts which have been transmitted to us, of the Egyptians, Chaldeans and Greeks.

But if the astronomy of the Hindus pretends to an antiquity which must be allowed to be of a doubtful character, their chronology, if understood literally, goes back beyond all the limits of probability. In the Institutes of Menu, the most ancient Sanscrit work in existence, and which Sir William Jones supposes to have been written 880 years Before Christ, is a passage from which we learn that this people supposed there had been, and would continue to be, an innumerable succession of periods of time, each consisting of many millions of years, and each terminated by a destruction and a re-formation of the universe. These periods are divided into yugas or ages of various lengths, but all of them are multiples of the least, which is called the Cali-yuga, and is said to be equal to 1200 years of the gods, each of which the Hindus pretend to be equal to 360 years of mankind, one of the latter years being supposed to be a day of the gods, and 360 such days constituting one of their years, according to this mode of reckoning, therefore, the Cali-yuga should consist of 432000 common years. Ten of these periods constitute one Maha-yuga, and one hundred or one thousand Maha-yugas, for the number is variously stated, make the period called calpa, which is said to be one day of Brahma. The Hindus suppose the present world to have been created at the commencement of this last period, and nearly half the period to be now past. The Maha-yuga is divided into four parts, of which the most ancient, called Satya-yuga, or the golden age, consists of four Cali-yugas; the next, called Trétá-yuga, or the silver age, consists of three, the third, called Dwápar-yuga, or the brazen age, of two; and the fourth is the Cali-yuga, in which we live; this is denominated the iron, or corrupt age; and these denominations afford another proof in addition to the many that may be offered of the propensity of men to consider the world as having deteriorated in the course of time, and their own, as worse than any of the preceding ages.

All Europeans who have commented upon these Hindu periods agree in considering them as astronomical, but they differ much in their manner of interpreting them; an imperfect knowledge of the retrogradation of the equinoctial points, which the Hindus, like the Arabians, supposed to be at the rate of 54 seconds yearly, might have led to an opinion that those points performed a revolution through the ecliptic in 24,000 years; and this period, multiplied by 18, which is the number of years expressing nearly the time of a revolution of the moon's nodes, would have given 432,000 years, the value of the fundamental cycle above mentioned: and Mr. Davis, in a dissertation on the astronomical calculations of the Hindus [a], argues, from passages in the Sourya Siddhanta, that the Maha-yuga is a period formed by the continual product of the times expressing the periodical revolutions of the equinoxes, of the moon's nodes and apogeum: he also considers the Calpa to express, in like manner, the time to elapse between two consecutive conjunctions of all the planets with their nodes and apogea, at the commencement of the zodiacal constellations. The values, moreover, which have been above assigned to the Hindu cycles do not appear to have been universally adopted in India; for, according to Mr. Crawford [b], the Hindus of Bali estimate the Maha-yuga at 15,025 years, instead of 4,320,000 years; and this period has, very probably, been formed from some erroneous determination respecting the movement of the equinoxes.

But though we should admit that the values of the above periods may have been given for those of certain astronomical cycles, it is no less probable that they have some relation to circumstances in the political history of the Hindus, the division of time into four ages is not peculiar to the people of India; indeed it was universally adopted by the ancients, and the periods in all cases seem to have designated the durations of particular races of sovereigns. Thus, in the fabulous chronology of Egypt given by Manetho, we find mention made of three ages, preceding those of the historical times, during which the throne of the country was said to have been occupied by gods, demi-gods and Manes: from the Zend-Avesta we learn that the ancient Persians

[a] Asiatic Researches, vol. ii. [b] Ibid. vol. xiii.

appropriated the three first of the four ages into which, as it is asserted, the supreme Deity had divided the duration of the world, to the Divis, the Peris and men, and the Hindus place in the three first of the above mentioned periods, respectively, the reigns of Gods, of Pidar Devata and of men: even the Chinese appear to have made a similar appropriation of the divisions of time, for, according to Pere de Mailla, three royal races are pretended to have succeeded each other in their country; the Tien-hong, or kings of heaven; the Ti-hong, or kings of the earth, and the Gin-hong, or kings of men, and these last are said to have terminated with Fohi The four ages mentioned by Hesiod[a], in which Jupiter successively created and destroyed four races of men, are familiar to every classical scholar

That the origin of the earth may be placed far beyond the epoch of our earliest histories, geological facts seem to prove; but, as no fossil remains of the human race are found, we have no reason to believe that the earth was the abode of man before the period assigned to his creation in the books of Moses · it is not, however, surprising that the ancients, if they held from tradition or otherwise, that the creation of the earth or universe had taken place in times very distant from their own, should have considered the human race to have existed also from a period equally remote, since a world unoccupied by intelligent beings must have appeared to be a work of the Deity without an object. The present state of the earth affords also indubitable evidence that it has been subject to several grand convulsions by which its external surface has been remodified; and we may reasonably suppose, that the time immediately preceding the creation of man was the epoch of one of these convulsions, while that of the Noachian deluge may be considered as marking the occurrence of another. Some early intimations of these changes, or a view of the constitution of the earth near its surface may, it is easy to conceive, from the propensity of mankind to multiply and embellish every natural circumstance of an extraordinary nature, have led the Hindus and Persians of old, to invent the fables related in their writings concerning the

[a] Opera et Dies.

vicissitudes experienced on the earth. Thus, among the former people, may have originated the story that the world was renewed, after a deluge, at the commencement of each menu, or period of 12,000 years, of which periods, it is said, the present is the seventh[a]. The author of the Persian manuscript, *Modjmel*, supposed to have been written in the twelfth century, also relates, from a work ascribed to Zoroaster, that the Supreme Deity had fixed 12,000 years for the renewal of the world, that the world remained free from evil during 3000 years, when Ahriman appeared, and then, during the next 3000 years prevailed a state of unmixed evil; from the end of the last period to the present time, the good and evil are said to have been blended together[b]: that there is some connection between the Hindu and Persian legends seems probable, from the equality of the periods just mentioned; and from the circumstance that, in one of the latter, according to Wilson, the bird Simurgh is introduced telling Caherman she had lived to see the earth seven times filled with creatures.

The observed movements of the sun and moon had anciently led to the measurement of short periods of time, as days, months and years, within which, many of the processes of nature are continually renewed, and it was natural to conclude, by analogy, that the general conjunctions of the planets and the revolutions of their nodes and apsides were epochs of the physical changes undergone by the earth itself.

Several works composed in the Sanscrit language and relating to the astronomy of the Hindus, have lately been made known to the Europeans, and of these, the most ancient extant is the Sourya Siddhanta, which is pretended by that people to have been revealed from Heaven two millions of years since, but which, from the composition of the tables it contains, and from the evidences afforded by their own histories can be shewn to have been written long since the commencement of the Christian era. Mr. Bentley, in a paper on the Hindu systems of Astronomy has examined the tables, and from the different elements of their construction, (among which are the assigned

[a] Wilson on the Chronology of the Hindus. Asiat. Research. vol. v.

[b] Zend. Avesta, Tom. II. Art. Boundehesch.

length of the year, the places of the planets, of the apogea of the sun and moon, and of the moon's nodes,) by comparison with the same elements computed from modern tables for different periods, he finds that the errors of the tables are the least at two epochs which are the years 499 and 999 After Christ; then, arguing that the errors of astronomical tables, if the elements are determined from observation, should be the least at the epoch for which they are formed, he infers that the tables and, consequently, the work itself may have been composed at a time not earlier than one or the other of these periods. It is to be observed that the *Bhasvotee*, another astronomical work, was, according to Bentley, composed about A. D. 1100 by Sotomund, who, it is alleged by the Brahmans, was a pupil of Varahà Mihira, the supposed author of the Sourya Siddhanta, and this circumstance would seem to shew that the latter astronomer lived, and that the Sourya Siddhanta was written about A. D. 1000, the last of the two epochs deduced from the tables. but Varaha is thought to have flourished at the earlier period, and, in a commentary on the work, the latter is expressly ascribed to him [a], the difficulty may, however, be removed by supposing that, in designating Sotomund as the pupil of Varaha, the Brahmans only meant that he was a disciple, in a subsequent age, of the school founded by that astronomer. Mr. Bentley also remarks that, from observations recorded in the Parasari Sanhita, compared with others made by Brahma Gupta, the author of an astronomical work entitled Brahma Siddhanta, in which Varaha is quoted by name, the solsticial colure had retrograded 23° 20′ in the interval between the observations: he supposes with the modern Brahmans that Brahma Gupta lived about A. D. 527; and as the above retrogradation corresponds to a period of 1680 years, it follows that the more ancient observation must have been made about the year 1153 B. C., and that Parasara must have flourished in the same age.

If the statements made in the Sourya Siddhanta may be depended on, we have the means of fixing with precision the point in the ecliptic which the Hindus considered as the origin of their fixed zodiac: since, according to Bentley, it is there assert-

[a] Asiatic Researches, Vol. VIII.

ed that the year 3601 of the Cali-yuga [A D. 499,] began precisely at the vernal equinox; which is conceived to imply that the sun was then at the commencement of the zodiacal constellations, and that the latter was in coincidence with the equinoctial point, because, it is known that the astronomical year of the Hindus was sidereal, and that it was the practice of this people to consider the arrival of the sun at the origin of the zodiac as the commencement of the year. Now, between A. D. 499 and A. D. 1820, [1321 years] reckoning the precession to be 50″.1 yearly, the equinoctial points must have retrograded 18° 23′ 3″, and, as the longitude of Aldebaran at the latter period is known to have been 67° 16′ 27″, it is evident that, at the former, the vernal equinox, and the origin of the Hindu zodiac must have been situated 48° 53′ 24″ westward of that star; that is near ζ Piscium, or about 12 degrees westward of the first remarkable star in the constellation Aries. And, again, computing the retrogradation of the equinoctial points for 3601 years, which are supposed to have elapsed between the commencement of the Cali-yuga and the year 499 of our era, we find it to be 50° 6′ 50″, or the vernal equinox was, at the former period 1° 13′ 26″ eastward of Aldebaran. The place thus found for the origin of the fixed zodiac agrees very nearly with that deduced from an observation of Brahma Gupta, for, according to Bentley, that astronomer makes the longitude of Spica Virginis equal to 6^s 3°, which indicates the beginning of the sixth century, and as the difference of longitude between this star and Aldebaran is known to be 4^s 14° 3′ 22″, the longitude of the latter, or its distance from the origin of the zodiac, at the same epoch, must have been 48° 56′ 38″.

But M. le Gentil learned from the Brahmans of Triavelore, a town on the coast of Coromandel, that 20,400 years before the commencement of the Cali-yuga, the fixed origin of the Hindu zodiac was in coincidence with the vernal equinox, when, also, the sun and moon was in conjunction, and that a like coincidence of the fixed and moveable zodiacs took place in the year 3600 of the same period[a]: now the sum of these is 24,000 years, within which the equinox must have been supposed to

[a] Bailly Astron. Ind. Chap. VIII. Sect. 5.

retrograde through the whole circumference of the ecliptic; consequently, they must have considered the annual precession as equal to 54 seconds, and, between the origin, and the year 3600 of the Cali-yuga, the equinoctial points must have been supposed to retrograde 54 degrees, which implies that the vernal equinox, at the former time, (3101 B. C.,) was situated at the distance of 5° 6′ 36″ eastward of Aldebaran, instead of 1° 13′ 26″ as found above. The difference is nearly 4 degrees, but it is impossible to determine whether it is caused by any error in the account given by Varaha, or in that which was communicated to Le Gentil: it is evident, however, that the coincidence asserted to have taken place, at the most ancient epoch, is only a result of computation, arrived at by reckoning backwards, from that mentioned by Varaha, with the erroneous value of the precession which the Brahmans had obtained by other means. M. Bailly admits that the epoch itself is fictitious, and formed from the supposed discovery that, in 20,400 years, there are very nearly 272,724 complete revolutions of the moon

From the place assigned to the winter solstice, by the Persian astronomer, Omar Cheyan, who lived in the year 1079 of our era, M. Bailly finds[a], by computation, that at the supposed invention of the Persian calendar, which he places in the year 3507 Before Christ, this point was in the 13th degree of the constellation Aquarius, while, at the same period, the corresponding point in the Hindu zodiac was in the first degree of the same constellation, and because, with respect to the fixed stars, the commencement of the Persian zodiac then coincided with that of the zodiac in the modern astronomy, he infers that the latter was adopted from the former; but when we consider the uncertain ground on which this supposed antiquity of the Persian calendar rests, we are forced to conclude, that this derivation of the European zodiac is nearly destitute of probability.

A representation of a Hindu zodiac was brought by M. Le Gentil to Europe, and is described in the *Memoires de l'Academie des Sciences* for 1772. It is divided[b] into twenty-seven nac-

[a] Astron Indienne, Disc. Prel. pag cliv. and Ch. ix. Sect 32.
[b] Ibid. Chap. v. sect. 30.

shatras, or constellations, and each division is, of course, equal to 13° 20′: one of them, denominated Rhonini, is distinguished by five stars, the easternmost of which, being the most remarkable, is supposed by Bailly to indicate the beginning or end of one of the said constellations, and he decides that it must be the end of the fourth, but four such divisions are equal in extent to 53° 20′; hence it would follow, that the star represents Aldebaran, which, as we have shewn above, is about 49 degrees eastward of the fixed origin of the zodiacal constellations; and, as the equinox is, in the monument, placed a little eastward of the star, it follows that it is about 54 degrees eastward of the commencement of the fixed zodiac; whence the epoch of the monument would appear to correspond with the commencement of the Cali-yuga: but the fact that the above star is really to be considered as Aldebaran, is evidently very doubtful, and, consequently, no reliance can be placed on the above conclusion. The division of the zodiac into twenty-seven constellations seems to have been but partially adopted in India; for in the writings of the Hindus, the number of nacshatras is generally made equal to twenty-eight, which is that of the lunar mansions in the astronomy of the Persians and Arabians. In their astronomical tables it appears, from the rules prescribed for finding the longitude of the sun, that the zodiac was also divided into 12 signs of 30 degrees each, like the zodiac of the Greeks; and each sign has been divided into three parts of 10 degrees each, like the decani of the western astrologers.

The same rules shew, also, that the astronomical year, both solar and lunar, was, by that people, divided into 360 fictitious days; and that the former was divided into twelve unequal months, so that each astronomical month contained the same number of days and fraction of a day that the sun takes to pass through each sign: a sexagesimal division of days, hours, &c. is also employed. But all the Hindu tables are formed on the supposition that the length of the sidereal year is equal to 365 days, 6 hours, 12′ 30″; and, as the annual precession of the equinoxes is also supposed to be 54 seconds, the tropical year must have been considered equal to 365 days, 5 hours, 50′ 35″: it is not known that this kind of year was, at any time, used in

India for civil or scientific purposes, but it is evidently implied in the luni-solar period containing 19 years, or 228 solar months, which, in the Siamese astronomy, as in that of the Greeks, is made equal to 235 lunar months: each of these lunar months is proved by Cassini, from the precepts delivered in the tables brought from Siam, to be equal to 29 days, 12 hours, 44′; whence he finds that the value of the tropical year must have been supposed equal to 365 days, 5 hours, 55′ 14″, which differs by only about 2 seconds from that found by Hipparchus and Ptolemy, from whom, we suspect, the above periods were borrowed. The present value of the tropical year, increased by 10 seconds, which, according to La Place, is the amount of the diminution of its length in the time elapsed since the commencement of the Cali-yuga, gives, for the value of the year in that age, 365 days, 5 hours, 48′ 58″, which is less than the supposed determination of the Hindus by 1′ 37″ only. If this is to be considered as a proof of the accuracy of their equinoctial or solstitial observations, it will be evident that the value of their sidereal year, which is an important element in their tables, and which they made too great by 3′ 18″, was merely computed, from that of the tropical year, by applying the erroneous precession [54″], and then it will follow that the construction of the tables was subsequent to the adoption of this value of the precession, which, in all probability, belonged originally to the Arabian school.

Of the astronomical tables received from India, the epoch of that which was brought by M. Le Gentil from Triavelore, boasts the highest antiquity, as it coincides with the commencement of the Cali-yuga, or rather with the second day after that commencement, and is found to correspond with the midnight between the 17th and 18th of February, in the year 3102 Before Christ: this particular year is known from the statements of the Brahmans themselves, who, according to Sir William Jones[a], assert that the year 1790 of our era coincided with the year 4891 of that cycle. We do not pretend to lay much stress on chronological coincidences, but Bailly considers that the date above assigned to the origin of the Hindu period is strongly

[a] Asiatic Res. vol. II.

confirmed by the fact, that the number of years which elapsed between that period and the times of Nabonasser and Yesdijird respectively, agree with those alleged by George of Trebizond to have intervened between the deluge of Noah and the last two epochs: now, as the Cali-yuga is said by the Hindu writers to have been preceded by a deluge, it seems to follow that the two deluges are identical, and, consequently, that the origin of the Cali-yuga and the deluge of Noah are to be referred to the same time, that is to the year 3102 Before Christ. But it should be observed that Bailly supposes his years to consist of 365 days only, and that this epoch is earlier by five or six hundred years than the date assigned to the general deluge by the commentators on the Hebrew Scriptures.

The epoch of the tables brought from Siam in 1688 by M. De la Loubiere, the French ambassador to that country, is found by Cassini to correspond with the time of the vernal equinox in the year 638 of our era, and those of two other sets of tables, which were sent from Chrisnabouram and Narsapour, are fixed for the years 1491 and 1656 respectively. The forms of these Hindu tables differ, but the elements of all appear to be the same; and it is thought that they were originally calculated for one meridian, which is that passing through Tiravelore. The tables brought from hence assign the places of the sun and moon at the epoch, their mean movements and those of the planets, they show the obliquity of the ecliptic, the length of the sidereal year, the equation of the centre for the sun and moon and the precession of the equinoxes, and they state that, at the same epoch, the sun, moon and all the planets were in conjunction. Now the longitudes assigned to the sun and moon differ but little from those determined for the year 3102 Before Christ by computing back, with the modern tables, but Bailly, calculating the places of the planets for the same epoch, or rather for fifteen days after it, (because the sun, at the time of the epoch, being supposed in conjunction with the planets, his light would have rendered them invisible,) finds that, except Venus which was on the opposite side of the heavens, all the other planets were within 17 degrees of the equinoctial point, the moon was then in opposition and, consequently, at the epoch,

she also was in, or nearly in conjunction. Now it must be admitted that the absence of one, only, of the planets and the presence of the others within 17 degrees of a certain point in the heavens might, to ordinary observers, be sufficient to justify the assertion that they were all in conjunction; but the coincidence of the places of the planets, determined by calculation, with those stated to have been observed, is a very insufficient proof of the reality of the observation, because, within such limits as those above specified, the Hindus might easily have computed a conjunction of the planets by using the Ptolemean or Arabian tables, which there is nothing to prevent us from supposing they had received before the existing tables of Triavelore were formed.

The latter tables, whose epoch we have said is more ancient than those of the others, are acknowledged to be more correctly constructed than the tables of Chrisnabouram, which are believed to be more modern by 4600 years, for Bailly observes[a] that these contain an empirical equation which is employed in determining the elements of the moon's orbit, and it is found that the elements thus determined agree very nearly with those obtained directly from the former tables, the inferences, therefore, are, that the Chrisnabouram tables could not have been computed from those of Triavelore, since, in this case, no such equation would have been required, and that the latter tables are the more modern of the two. To avoid this conclusion Bailly is compelled to allow that the Triavelore tables have been rectified by new observations since their original construction, but this being admitted, all confidence in the alleged antiquity of the tables is destroyed, and it will be as easy to admit that the construction itself is of recent date. It is alleged by the Brahmans themselves that in the days of Salivaganam, who lived in the year 3179 of the Cali-yuga, or in the year 78 of our era, their astronomy underwent a complete change and, if the epoch of that prince be correctly stated, it affords a presumption that the reformation took place by the introduction of the discoveries of Hipparchus.

The estimates formed by the Hindus of the movements of

[a] Astr Ind. Chap. II sect. 24.

the equinoctial points appear to have been as uncertain as those of the Arabians, from which, indeed, they do not materially differ. Mr. Colebrook states[a], that according to Bhascara, (who wrote in the twelfth century of our era,) in his description of the armillary sphere, "the equinoctial points revolve, in retrograde order, three myriads in a calpa"; meaning, probably, that 30,000 complete revolutions take place in that period; and, if we suppose the latter to consist of 432,000,000 years, as before shown, the expression will imply that the points retrograde at the rate of one degree in forty years. But, on the authority of the more ancient astronomer *Munjala*, Bhascara relates that a revolution of the colures through the twelve signs takes place at the rate of 59″ 54‴ yearly, or of one degree in 61 years: except Munjala, however, it appears that Vishnu-Chandra is the only Hindu author, more ancient than Bhascara, who is thought to have maintained the opinion that the motion of the equinoxes was constantly retrograde, and we have before stated that, from a work ascribed to Aryabhatta, and quoted by Muniswara, as well as from passages in the Sourya Siddhanta and other works, probably of the same age as this last, the notion of a libration of the equinoctial points, within the limits of 24, or 27 degrees on each side of their mean places, was long prevalent in India; in fact, Muniswara himself, who wrote a commentary on Bhascara's work, and therefore must have lived in a later age, rejects the doctrine of the latter author, and asserts the reality of the libration. But nothing of this kind appears in the astronomical tables of the Hindus, in all of which the precession of the stars in longitude is supposed to be uniform, and at the rate of 54 seconds yearly; and the coincidence of this value with that given in the works of the Arabian astronomers, can only be accounted for by supposing that this element had been adopted from those works without examination; for if we allow that the above-mentioned tables are formed from data afforded by a long series of observations, agreeably to the hypothesis of the advocates for the antiquity of the Hindu astronomy, a more correct determination of the element must have been obtained by a comparison of the places of any one fixed star, when found at

[a] Asiat. Res. vol. XII

long intervals of time. It has been supposed that, previously to this adoption, the Hindus used a value of the precession equal to that stated by Ptolemy; for, according to M. De Guignes, there is an account, in a work of the Arabian writer *Massoudi*, that the Hindus had been taught astronomy by Brahma, who showed them that the sun (at the times of the equinoxes or solstices) remained 3000 years in each sign of the zodiac, which supposes that a complete revolution of the equinoctial points was accomplished in 36,000 years, and that the annual precession was 36 seconds. That the Hindus had, at one time, a nearly correct knowledge of the precession, has been inferred from a passage cited by Ricius[a], out of the Jewish writer, Abraham Zacuth, who lived in the 15th century, where it is said that, according to the Hindus, there are in the heavens two stars diametrically opposed to each other, which describe the circuit of the zodiac in 144 years, contrary to the order of the signs, now if there be a mistake in the direction of the motion, and we are allowed to read *according to the order of the signs;* and if, besides, we suppose with Bailly, that the years are periods, each equal to 180 common years, like those said to have been in use among the Monguls and Chinese, the revolution would have been performed in 25,920 years, which is the time of a revolution of the fixed stars with respect to the equinox, at the rate of 51 seconds annually, and is not far from the truth. It is evident that these hypotheses rest on no solid foundation, but there can be no reason to doubt that the Hindus had discovered, or taken from the works now lost, of Chaldean, Egyptian, or Greek writers, a certain value of the precession; and it is probable that the variable duration of the *yugas*, or periods in which the numbers of revolutions are said to have taken place, mistakes in the numerals, and in the direction of the motion, besides other causes, have produced that confusion in this element which we find in their writings. At the time of the construction or reformation of the tables, the Hindus probably adopted the value of the precession which had been determined by the Arabians.

In examining the elements of the sun, moon and planets,

[a] Tractatus de motu octavæ sphæræ, cap. ix.

contained in the Hindu tables, we shall find that the proofs of antiquity drawn from comparisons made with the values assigned to those elements by late observations, or by computations founded on the theory of gravitation, are liable to great uncertainty and may, even, be considered as destitute of any foundation, partly because the coincidences do not hold good in all the elements and partly, because, in those which have been observed, if the necessary corrections had been made, the errors would have been more considerable; to which we may add that a near approach to coincidence, when the variations of an element amount only to a few seconds in many centuries, does not constitute, within narrower limits, the determination of a particular epoch. This is the case with the length of the tropical year abovementioned, which has been shewn to differ from its true value by 97 seconds only, for since, from the epoch of the Cali-yuga to the present time, that is during above 4900 years, the whole decrease in the length of the year is but 10 seconds, the above error which, if considered alone, might appear inconsiderable, is really far greater than the diminution due to the whole of that long period; and the supposed length of the year, instead of corresponding, nearly, to the epoch of the tables, indicates one which is above 45,000 years from our times.

Again, from the same tables we find that the obliquity of the ecliptic is stated to be 24 degrees· and, by computation, it is found that, at the epoch of the tables, it was really equal to 23° 51′; the error, which is but 9 minutes, appears but small, but, as the diminution of that element is at the rate of 50 seconds in a century, that error corresponds to nearly 1100 years in time, and if we could suppose the value given in the Hindu tables to be accurate, the observation on which it is founded must have been made so much earlier than that epoch. But it is much more probable that the 24 degrees had been assumed for the sake of the exact number, and it should be observed that the same value was given to the element by the earliest astronomers among the Greeks. An objection founded on the slow change of value in the element, may, also, be urged against the argument for the antiquity of the tables, drawn

from the value of the moon's anomalistic revolution, which is shewn to agree, within one third of a second, with that determined by recent calculations made for the commencement of the Cali-yuga. Bailly suggests that the two former elements, the length of the year and the obliquity of the ecliptic, may have been determined from observations made long before that period, but there is no one age to which both can be referred, and it is incompatible with the opinion that the Hindu astronomy was in an advanced state when the tables were formed, to suppose that there may have been introduced in those tables the values of elements belonging to different epochs.

The maximum equation of the sun's centre, taken by Bailly from the tables of Narsapour and Chrisnabouram, and supposed by him to coincide with that which is involved in those of Triavelore, is 2° 10′ 30″, while by late observations it is found, in the present age, to be only 1° 55′ 30″, now the diminution of this element is known to be at the rate of about 15 seconds in a century, and the inference is that the epoch at which the above value of the element held good is about 6000 years since. But it is observed by La Place that, as the Hindus determined the elements of the solar orbit by means of the eclipses of the sun or moon, their equation of the centre should include the moon's annual equation, which is 11 minutes, and this would reduce the above value to 1° 59′ 30″, which would give, for the epoch of the tables, the year 200 of our era. Nearly the same epoch is found from the place of the sun's apogeum which, by the times of the continuance of that luminary in each sign of the zodiac, given in the tables, appears to have been somewhere in Gemini while the longitude of the apogeum, in the present age, is 3ˢ 9° 30′, and the rate of its motion with respect to the equinox is about 68 seconds annually.

M. Bailly is not more fortunate in the conclusion he draws from the determination made by the Hindus of the moon's mean motion. In the preliminary discourse to the *Astronomie Indienne*, he states that, in the interval of 4384 years 94 days, ending May 21, A.D 1282, the tables of Triavelore give for the sidereal motion of that luminary 7ˢ 2° 0′ 7″, rejecting whole

circumferences, and, because this agrees, within one minute, with what would result from the mean motions computed by the tables of Cassini and Mayer, he infers that it must have been obtained from observations made at the beginning and end of the period, but it happens that these tables do not comprehend the equation discovered by La Place, which, in the same interval, would amount to about 4 degrees; consequently, the argument in favour of the antiquity of the first-supposed observation, falls to the ground.

The places of the aphelia of the orbits of Jupiter and Mercury, given in the Hindu tables for the commencement of the Cali-yuga, certainly agree with the results of computation made from the best modern tables; but, as these elements are materially affected by the masses of the planets, which are, even now, uncertain, it is impossible to draw any conclusion, from that agreement, concerning the reality of the observations on which the elements are supposed to have been founded.

The mean movements of Jupiter and Saturn are known to be subject to variations which become compensated at the end of certain long periods, fixed by La Place[a] at 929 years, and are such that, within each alternate period, the motion of one of the planets is the most rapid, and that of the other, the most slow: now it must be admitted that the quantities assigned to the mean motions of Jupiter and Saturn in the Hindu tables, for the epoch of the Cali-yuga are justly alleged by Bailly to agree with the results of the theory of gravitation in shewing that the former was then a maximum and the latter a minimum; but this fact which would seem, at first sight, conclusive in favour of the supposed antiquity of the tables leave the question still indeterminate; since, if we reckon backward from the year 1491 of our era, which is the epoch of the Chrisnabouram tables, five times the above period would bring us to the year 3154 Before Christ, which is near enough to the epoch of the tables of Triavelore to allow us to conclude that, at both epochs, the mean movements of these planets must have been, respectively, the same; the probability, therefore, that these tables were con-

[a] Exposition du Système du Monde, Liv. IV. chap 2.

structed at the more ancient period is not, in this respect, greater than that of their construction at the other. It ought also to be observed that, in the tables, the equations of the centre for the orbits of both these planets, by which the mean is reduced to the true movement, differ considerably from the truth, and Bailly supposes, though without any evidence, that the original values have been vitiated by the Brahmans in later times. The approximations to coincidence with the results of calculation, observed in the preceding elements of the planetary orbits, do not take place in any of the others; and the differences found to exist, on making the comparison, cannot but destroy the conclusion which might have been drawn from the former agreements, for if we are to allow that all the elements were obtained from observation, it would follow that they should all correspond equally with the determinations of theory. By whatever means obtained, the elements of the sun and moon are given in the tables with considerable accuracy, and to those elements, probably, the Hindu astronomers principally directed their attention: the phenomena of the planets being less available for civil or religious purposes, the movements of these celestial bodies may have been less constantly studied.

The astronomy of the Hindus may be said to resemble in many respects that of other ancient nations, particularly of the Greeks, from whom there is good reason to believe they have borrowed their planetary system. From Mr. Colebrook's paper *On the notions of the Hindu Astronomers*[a], we learn that the Hindus place the earth in the centre of the universe, and suppose the sun, moon and planets to revolve about it in circular orbits, with uniform velocities; and that in order to explain, on mathematical principles, the inequality of the planetary motions, they suppose the earth to be at a distance from the centre of each of the orbits, which, therefore, may be considered as eccentric circles. In the Sourya Siddhanta is described a system of eccentric deferents with epicycles, very much resembling the system of Ptolemy; the principal difference being that the epicycle is said to have been supposed of an oval figure. The

[a] Asiatic Researches, Vol. XII.

planet is imagined to move on the epicycle with a velocity equal, and in a contrary direction, to that of the epicycle on the deferent, and the epicycles belonging to Jupiter and Saturn are said to have their minor axes in the line of the mean conjunction of their respective planet with the sun. The dimensions of the epicycles are computed by Bhascara, but this astronomer describes the deferents as the true orbits of the planets, and observes that the epicycles were merely devised for the purpose of facilitating the calculation of the true places.

This description of the planetary system of the Hindus corresponds nearly with that idea of a system, which has been drawn from the construction of their astronomical tables. M. Bailly observes that, in the precepts relating to the tables, the rule for reducing the mean to the true place of the sun, moon or a planet by the equation of the centre, makes it evident that the orbits of all must have been supposed to be eccentric; and he adds that, in finding the place of a planet, the Hindus use a fictitious longitude found by the continual addition of the mean longitude, half the equation of the centre and half the parallax of the annual orbit; which he conceives to imply that the inequalities were referred, not to the earth, or the centre of the system, but to an angular point mid-way between the sun and the earth, and corresponding to the centre of the equant in the system of Ptolemy: Mr. Colebrook is, probably, therefore, mistaken when he supposes that there is no equant in the Hindu astronomy. This fictitious longitude is not, however, used in finding the true places of the sun and moon, and M. Bailly, from thence, supposes that the orbits of these were considered as simple eccentric circles.

The attempt of the Hindus to explain from physical causes the movements of the planets scarcely deserve to be noticed; but the following account of their opinions respecting this subject, as stated in the Sourya Siddhanta, is given by Mr. Colebrook in the paper above mentioned. They imagine that the planets are driven by movements of air along their respective orbits, and that there is one great vortex carrying the stars and planets with prodigious velocity round the earth in one day: the

winds or currents impelling the planets are supposed to be such as would cause them to move always in the plane of ecliptic, and with equable velocities, but it is imagined that the planets are drawn from their courses by certain controlling powers situated at the points of apogeum and conjunction, and at the nodes of the orbits, and these powers are described as divinities or invisible planets.

We are informed by Bailly, that the Brahmans suppose the earth to rest on a golden mountain, at the centre of the universe, and seven worlds or planets to revolve about it; the moon is placed nearest the earth, then follow in succession, Mercury, Venus, the sun, &c., as in the systems of the Chaldeans and Ptolemy; but this arrangement does not appear to have at all times prevailed, for in the Bhaga Vadam which, though an apocryphal work, probably contains notions at some time prevalent in India, the Hindus like the ancient Persians are said to have supposed the moon to be more remote than the sun, probably because it gives less light and heat, and the stars to be fish swimming in ether. In a representation of the solar system made by some modern Brahmans there are described, beyond the orbit of Saturn, two circles bearing the names of *Natchattar* and *Akash;* and it is probable that these represent the orbits of some of those imaginary bodies, or divinities, which were supposed to disturb the motions of the sun and planets. According to Buchannan, the Burmese entertain an idea that, beyond Saturn there is an invisible planet named *Rahu*, or the Dragon[a], and it is probable this may be identical with a body supposed to move in one of the orbits just mentioned. The vulgar in India are of opinion that eclipses are caused by the intervention of a monster bearing this name.

On contemplating the monuments of Hindu astronomy we can hardly avoid admitting that India must have been once possessed by a race of men more energetic than those who now occupy that fine country. Besides the tables above mentioned which, if not entirely original, must have been laboriously constructed with materials furnished by the works of another people, their treatises on arithmetic, algebra, and geometry, are proofs

[a] As. Res Vol. VI.

of intense application to the pure sciences; and though very few of their astronomical observations now remain, yet, from many hints in their writings, it is evident that these had not been neglected. A Hindu writer, in commenting upon a passage in the Sourya Siddhanta, where it is prescribed that the astronomer should form a sphere by which to examine the apparent longitudes and latitudes of stars, (evidently designating a sphere similar to the armillary instruments mentioned by Ptolemy,) observes that there should be an additional circle graduated in degrees and minutes and suspended on the axis; this is denominated an intersecting circle and is, apparently, a circle of declination; and in rectifying the sphere, it is directed that the axis should be pointed to the pole, and that the horizon should be made true by a water level. The instrument being thus placed, the observer is to look for the star *Revati* through a sight adjusted to an orifice at the centre of the sphere; and having found it, the extremity of the sign *Revati*, on the ecliptic circle of the instrument, is to be brought to coincide with the direction of the line of sight. The latter is, next, to be turned to the star whose position is required, and the moveable circle of declination is to be made to pass through the star; then the distance, in degrees, from the extremity of *Revati* on the instrument to the intersection of the circle of declination and the ecliptic, will be the *longitude;* and the number of degrees on the circle of declination reckoned from the same intersection to the place of the star will be the *latitude*[a]. The sign Revati is said by Mr Colebrook to be the last of the twenty-eight asterisms into which the Hindu zodiac is divided; and the star called by that name he conceives to be that now designed *ζ Piscium;* which, agreeably to a deduction from an observation ascribed to Brahma Gupta, and to an hypothesis of Bailly[b], was situated at the commencement of the fixed zodiac; and, if the vernal equinox coincided with the place of this star at the time when the above description was composed, it would follow that the said time corresponds nearly with the year 500 A. C. The mathematicians of India, like those of other countries, sup-

[a] Colebrook on the Hindu division of the Zodiac, As Res vol. IX.

[b] Astron. Indienne, chap. V. sect. 30. vide suprà, page 320.

posed the circumference of a circle of the sphere to be divided into three hundred and sixty degrees; and, like the Greeks, they distinguished a degree by a word signifying a part.

Soon after the dynasty of the Abbasides became possessed of the throne of Bagdad, the court of those princes was honoured by the presence of many distinguished philosophers, from foreign countries, by whom literature and science were introduced among the disciples of Mohammed. That the astronomical writings of Hipparchus, of Ptolemy, and of those who followed the latter in the school of Alexandria were then studied by the Arabians, is well known, and, as the arms of the Moslems had then recently subdued the northern part of India as far as the Ganges, it is quite reasonable to suppose that the learned men of that part of Asia would find many inducements to seek the patronage of the Khalif Al Maimon and his successors, and carry to the rising metropolis of the East their scientific works and their skill in the art of observing the heavens; an art which, subsequently to the decline of astronomy in Egypt and the eastern parts of Europe, they seem to have diligently practised. It is even related by Ebn Al Adami that Mohammed ben Musa, the author of a treatise on algebra (recently translated by Mr. Rosas) had abridged, at the request of Al Maimon, the astronomical tables contained in the work of some Hindu astronomer who visited the court of Almansor in the year 773 A. C. The use of the gnomon and astrolabe, which probably had ceased in the west, was therefore revived by the Arabians from the instructions communicated to them by their Hindu teachers; and hence the former people, in describing their instruments of observation, so frequently, by their manner of designating them, shew that they considered them of Hindu origin. The circle traced at the foot of a gnomon to determine the meridian by the equality of the shadows is called by Ibn Jounis the Hindu circle; and this astronomer adds that one of the kind, which he had described for himself, was traced on a pavement of white marble, while that of the Hindus was on sand; other Arabian writers, also, in describing the astrolabe, apply to it a like denomination.

The science cultivated, apparently with so much zeal and

industry, by the ancients, in Chaldea and Egypt, is not likely to have been confined to those countries: the conquest of Egypt by Cambyses, and of India by Darius Hystaspes, the connections of the Ionian States with the court of Persia, and lastly, the expedition of Alexander the Great, must have given rise to so much communication between the different people inhabiting the territories lying between Italy and the Ganges as to render it impossible that the discoveries made by any one of them, in astronomy, which possesses so many points of equal interest to all men, should not have been almost immediately adopted by the others, and incorporated with the elements which they previously possessed. Thus the cycles discovered by the Chaldeans or Egyptians, who may be considered as the earliest observers, may, unless we adopt the hypothesis of independent discoveries, have been communicated at the same time to the predecessors of Hipparchus, in Greece, and to those of Aryabhatta in India: and the state in which they were received in the latter country; probably in, or previously to the age of the Vedas, may be collected from the ancient treatises on astronomy which are attached to the several works bearing that denomination. These treatises relate to the adjustments of the calendar and the comparison of solar and lunar time for the formation of the civil year; and from them it appears that in a period of five years, the moon was supposed to make 67 revolutions to the same fixed star, *or to the equinox*, (an expression from which Mr. Bentley infers that, at this time, the Hindus had no knowledge of, or disregarded the precession of the stars,) and 62 revolutions with respect to the sun. The number of solar days assigned to the cycle just mentioned is stated to be 1830; and, therefore, the duration of a synodical revolution of the moon must have been supposed equal to $\frac{1830}{62}$, or to $29\frac{16}{31}$ days; comparing this with the known length of such a revolution, the error is found to amount to one day in six years, from which Bentley also concludes that the Hindus could not then have been able to determine the times of the conjunction and opposition of the sun and moon for six years in advance; much less could they have ascertained by computation the times of the eclipses of the luminaries. In the

regulation of the calendar, the rules given in the Vedas prescribed that a month should be doubled in the middle and at the end of the quinquennial period, which consequently consists of three common lunar years and of two, containing, each, thirteen lunations: the year is divided into six seasons, and each month into two half months; the day also, is said to consist of 30 hours, a division which, according to Achilles Tatius[a], was in use among the Chaldeans, and each hour, of 60 minutes. The zodiac is, moreover, divided into 27 signs, and the first is said to include the cluster of stars denominated *Crittica* which is supposed to signify the Pleiades[b]: this supposition however, is at variance with the general opinion concerning the place at which the Hindu zodiac commenced, but it is probable that the latter did not become fixed till long after the age of which we are speaking. In a note, Mr. Colebrook observes that the cycle of 5 years is mentioned by the name of *Yuga* in Parasara's Institutes, and it is there stated to be the basis of calculation for greater cycles, from this, the cycle of 60 years [12 × 5], so much used in the east, was probably formed, and subsequently, from the latter arose the cycle of 3600 years [60 × 60], which was denominated the Yuga of *Vacpati;* sixty of these, or 216,000 years, constitute the Yuga of *Prajanatha,* and the double of this last is the value of the *Cali-yuga.*

The cycles of 60 years, and 3600 years, here mentioned are identical with the Sossos and Saros of the Chaldeans, and from them, the Hindus may have formed some of their longer periods by the aid of their own observations on the celestial phenomena; in like manner, the restitutions of the moon's inequalities of motion may have been adopted by the latter people from those discovered by the former before the time of Aristotle. The Hindu periods, though not the same in quantity as those which have been preserved by Geminus, and which we consider as the bases of the lunar theory of Hipparchus, are precisely the same in kind; and may easily have been formed from the others, according to their own estimates of the length of the solar year and of the age of the world, by the learned astrono-

[a] Isagoge, cap. 18, in Petav. Uranol. [b] Asiat. Res. vol. VIII

mers of India who are mentioned by Brahma Gupta, and whom Mr Colebrook supposes to have lived about the times of Hipparchus and Ptolemy. According to the Narsapour tables, 800 [sidereal] years contain 292,207 days, and from this it is evident that the Hindu sidereal year was equal to 365 25875 days. Besides the cycle of 19 years, in which are contained 235 lunations, the Hindus had two periods; the one of 12,362 days, and the other of 21,857 days, in which respectively, they found that the moon had made 453, and 800 sidereal revolutions; and three periods in which she made, as they supposed, an exact number of revolutions with respect to the apogeum; the first of these was equal to 248 days, and contained 9 revolutions; the second to 3031 days, and contained 110 revolutions; the third to 12,372 days, in which were 449 revolutions; and these cycles were, most probably, employed subsequently in the construction of the tables of the movements of the sun and moon, which, in the last century, and after many reformations, were received in Europe. With respect to the planetary periods, Mr. Colebrook is of opinion that the Hindus merely surmised that the nodes and apsides of those celestial bodies were in movement, from analogy with the corresponding motions of the moon's orbit: he conceives that they were unable to verify their conjecture by observation, and that they have merely assigned arbitrary numbers to the supposed revolutions, in order to bring the places right, or nearly so, conformably to their assumption of a great conjunction of the planets with their nodes and apsides, in a certain point of the ecliptic, at a very remote period.

In a paper on the Hindu systems of astronomy[a] there is given a table of the restitutions of the solar, lunar, and planetary inequalities, according to the periods ascribed to Brahma-Gupta; from which it appears that in a Calpa, or in 4320 millions of years, the apsides of the solar orbit made 480, and the equinoctial points 199,669 complete revolutions [the mean movement of the latter must consequently have been supposed equal to 59″·7 yearly]; that, in the same time, the moon made

[a] Asiat. Res. Vol. VIII.

57,753,300,000 synodical revolutions, her apsides, 488,105,858; and her nodes, 232,311,168 revolutions. Mr. Davis finds, from the treatise ascribed to Brahma-Gupta, and also from the Siddhanta Siromani, that the number of days contained in a Calpa was supposed to be 1,577,916,450,000, whence consequently, the length of the sidereal year must have been considered equal to 365.25844 days.

Like Hipparchus, the Hindus determined the inequalities of the moon's motion by means of eclipses; and, hence, their theory is destitute of the equation of evection which was discovered by Ptolemy from observations made at the quadratures; this discovery, by some chance, never found its way into the astronomy of India and, in all probability, an attachment to the ancient method of observing prevented the people of India from attempting a comparison of the observed and calculated places of the moon when she was in any other position than the syzygies. We have said that they once had a value of the precession equal to that assigned by Ptolemy; and it is to be observed that, like him, in computing the true places of the planets, they suppose the conjunctions and oppositions to be referred to the mean place of the sun, instead of the true place, and the mean longitudes of Mercury and Venus to be the same as that of the sun. Lastly, in the tables of Triavelore and of Siam, the apogeum is supposed to be fixed in space, and in all these respects, there is a close conformity with the astronomy of Ptolemy, though there is no reason to doubt that all the above circumstances belong equally to the age of Hipparchus, if not to one still earlier. But the remaining elements belong to an astronomy of a later day than that of Ptolemy, and it is probable that the Hindus received the works of the latter astronomer only through the medium of the Arabian writers and, of course, accompanied by all or many of the changes which they had introduced in the science, their solar equations differ from those of the Greeks and Arabians, as if they had been formed by taking arithmetical means between the values assigned by both these people, they discovered, or adopted from the latter, the particular movements of the apogea of the Sun, Jupiter and Mercury, which Ptolemy considered as fixed in space, and their

precession of the equinoctial points is actually that of Albategnius nor can it be doubted that the lunar tables of the Hindus were formed posteriorly to the time of Ptolemy, because the mean motions of the moon with respect to the apogeum, the nodes and the sun, are, in these tables, found to be more rapid than in those of the Greek astronomers: and these movements are known to increase with the lapse of time. We may observe, therefore, that though the elements of the Hindus tables have not been formed immediately from those of the Greeks and Arabians, which, indeed, is proved by Mr. Playfair from the want of coincidence in the assigned places of the sun and moon at the supposed epoch of the Triavelore tables with the places determined by computation from the tables of Ptolemy and Ibn Jounis, yet there is nothing to prevent us from concluding that the astronomy of India, originally that of the ancient people of Western Asia, has received successive corrections from the discoveries made by natives and foreigners, and has been remodelled at various periods, down to the end of the seventeenth century.

With the Mohammedan power, the science of India declined and, notwithstanding the patronage afforded by the emperors Akbar and Aurengzebe, and the magnificent observatory erected at Benares by the rajah Jay Sing, it has not, since, been revived in that country.

CHAPTER XVI

THE ANCIENT ASTRONOMY OF CHINA.

A conjunction of the planets taken as an epoch by the Chinese.—The commencement of the Chinese year at one time coincided with that of the Hindus.—A regulation of the seasons by the Emperor Yao.—Ancient observations made in China with the gnomon.—Destruction of the Chinese writings.—The Chinese histories contain catalogues of celestial phenomena. Alleged resemblances of the Chinese sphere and those of the Hindus and Egyptians.—Divisions of time in use among the Peruvians and Mexicans.

THE astronomy of China may vie with that of India in the remoteness and obscurity of its origin, and, like the latter, it is supposed to have commenced with a primitive epoch at which the sun, moon, and several planets were in conjunction. In a Chinese work alleged to have been composed about the year 204 Before Christ, this conjunction is said to have been observed or predicted by the Emperor Tchuen-hi, and to have taken place in the constellation *Xi*; and the writer asserts that 143,127 years had elapsed between the time of the conjunction and that in which he lived[a]; now M. Bailly disregarding that pretended interval of time, has found by computation[b] that Mars, Jupiter, Saturn and Mercury were together, on the morning of February 28, Julian reckoning, in the year 2449 B.C. in a part of the heavens situated, in longitude, between the eighth and twenty-fifth degree of the sign Pisces, a space which must have been, then, comprehended between the star α *Arietis* and the Pleiades: and hence it is inferred that this portion of the zodiac must have coincided with the Chinese constellation *Xi*. The same astronomer found, also, that a conjunction of the sun and moon took place on the same day, in the nineteenth degree of the sign Aquarius, or near the star ζ Piscium; these he conceives, therefore, to have been the phenomena alluded to, which is not improbable since historians have placed in the

[a] Martini Historia Sinica, Tom. I. [b] Astr. Ind. Chap. IX. sect. 2.

same age the reign of the above mentioned monarch. According to Père De Mailla, who translated the *Annals of the Empire,* Tchuen-hi collected all the ancient observations which had been made in the country and gave precepts for computing the motions of the sun, moon, and planets, and it appears from the expression in the original work that, during the reign of this prince, and in the year which was distinguished by the above-mentioned conjunction of the planets, the first day of the spring quarter, by which we are to understand the commencement of the year, occurred previously to the first day of the first moon. Mailla, who finds by computation[a] that the conjunction took place in 2461 B. C. makes the time of new moon two days later than the arrival of the sun at a point in the ecliptic whose longitude was $10^s\ 15°$, which, then, nearly coincided with the star ζ Piscium, that is with the first point in the fixed zodiac of the Hindus: now the ancient Chinese always made their spring commence when the sun had that longitude, or was 45 degrees westward of the equinoctial point; it follows therefore that, in the time of Tchuen-hi, the place of the sun at the beginning of the Chinese year, and the origin of the Hindu zodiac were identical; and Bailly thence infers that the coincidence was the result of design on the part of the prince; no other reason, he observes, can be given why the year should be made to begin when the sun was in a part of the heavens which is not distinguished by any remarkable star, nor coincided with either of the equinoctial or solstitial points, and the circumstance may be considered favourable to the opinion that the astronomy of China was derived, at some period, from that of India; or that the people of both countries drew their knowledge of the science from a common source. The origin of the Chinese fixed zodiac, or the commencement of their constellation *Hiu,* is not however the same as that of the Hindus; it is supposed by Père Glaubil to have coincided, in the time of the Emperor Yao, with the place of the winter solstice; and, if we adopt Bailly's opinion of the age in which this prince lived, that place must have been about the middle of the constellation Aquarius.

[a] Hist. Gen. de la Chine, Tom. I.

From the abstract of the Chinese History given by M. de Guignes we learn that the emperor Yao, along with the other measures adopted for the improvement of his people, promoted among them the study of astronomy, and he particularly applied himself to the correction of the calendar, he directed that the length of the year should be 365 days and, to determine the seasons, he appointed the use of an intercalary moon, probably signifying that an additional month, or 30 days, was to be introduced every 120 years. From the means he proposed for distinguishing the commencements of the seasons an effort has been made to ascertain the age in which he lived, according to Pere Souciet[a], he prescribed that the equality of the days and nights and the constellations *Niao* and *Hiu* should indicate the vernal and autumnal seasons respectively, and the longest and shortest days with the constellations *Ho* and *Mao* should mark, respectively, the summer and winter Now, of these constellations, it is known that Mao designates the Pleiades, and, as all the four should be in or near the cardinal points of the ecliptic, it will follow that *Ho* must coincide with the beginning of Scorpio, *Niao* with the beginning of Leo, and *Hiu* with that of Aquarius, but it is doubtful in what sense these constellations were to indicate the seasons; for, if we suppose that their heliacal risings or settings took place on the respective days of the equinoxes or solstices, the epoch would be so remote as to be beyond the bounds of probability· it has, therefore, been considered that those days were indicated by the arrival of the constellations on the meridian soon after sunset, and if, agreeably to this supposition, we place on the meridian a point of the ecliptic whose longitude is 100 degrees, in which case the vernal equinox would be about 10 degrees below the horizon towards the West, the time at which the constellation *Niao*, or the first stars of Leo (whose longitudes are now about 150 degrees) occupied the point on the meridian, would be about the year 1800 Before Christ, hence the reign of Yao may be placed at that period, and M. Bailly by a similar supposition places it about 500 years earlier, but it must be owned that, since the

[a] Observations Mathematiques Astronomiques, etc., tirées des livres Chinois.

supposition may be varied considerably, the result obtained from this kind of estimate is extremely uncertain.

If what has been above ascribed to Yao be correct we may conclude with La Place that, in the time of this prince, the astronomers of China must have observed the arrival of the sun at the equinoxes or solstices and the transits, or passages, of stars over the meridian, but it should also be remarked that in such observations no great precision was necessary nor, probably, attempted. Before the time of Yao, a representation of the heavens on the surface of a sphere is said to have been made by one of the sovereigns of the country, but modern writers have ascertained that the word formerly translated sphere is the same as that used to signify the cover of a vessel, and the most that can be inferred from the account is that, in some remote age, there had been formed, in China, a sort of planisphere exhibiting rudely, like those of Egypt, a view of the constellations, or some of the principal stars.

From a Chinese MS sent by Père Glaubil to M Delisle, it appears that the regent Tcheou-Kong, who is said to have lived between the years 1104 and 1098 Before Christ, caused a number of observations to be made, and three, on the lengths of the meridional shadows cast at the times of the winter and summer solstices by a gnomon which was set up at Loyang in the province of Honan, have, fortunately, been preserved. From these, La Place, after making the necessary corrections for the sun's semidiameter, for refraction and parallax, has determined the latitude of the place of observation to be 34° 47′ 10″, north, and the obliquity of the ecliptic, 23° 54′ 3″, and, supposing the observations to have been made in the year 1100 Before Christ, the value of this element exceeds that which is found, for the same period, from the formulæ in the Mecanique Celeste, by 2′ 4″ only, a difference which is inconsiderable: but nothing is more uncertain from the dubious light afforded by the Chinese histories, than the age in which that prince is supposed to have lived, and the rude nature of the observations renders the evidence resulting from the near coincidence of the values of the obliquity any thing but conclusive.

The use of the gnomon must, however, be admitted to have

been very ancient among the Chinese, but the first notice obtained concerning it, from any of their written works, is that given in the Tcheou-li, which is said to have been composed two hundred years before Christ, it is there stated that the length of the shadow, at noon, is less than at any other time, on a given day, that the meridional shadow becomes longer as we proceed towards the north, and that, in proceeding towards the east, the shadow arrives earlier at the minimum. The particular gnomon alluded to is said to have been 8 feet high and to have consisted of a vertical pillar with a graduated horizontal bar, at its lower extremity, by which the angular distance of the celestial body from the zenith might be computed; and Cocheou Kong, who lived in the year 1280 of our era, erected one whose height was 40 feet and by which the obliquity of the ecliptic was found, in his days, to be 23° 33′ 40″: between the ages of Tcheou Kong and of the last mentioned prince three other observations of the obliquity of the ecliptic appear to have been made; the first in the year 50 Before Christ, and the others in the years 460 and 630 since the commencement of our era; all in the same manner, and, which is the best proof of the reality of the observations, all agreeing in the indication of a progressive diminution of that element. The Jesuit missionaries from whom so much information has been obtained concerning the state of the sciences in China, allege that Clepsydræ were used at a period as remote as the age of Yao for measuring time and the divisions of the zodiac, and they describe a machine having some resemblance to an armillary sphere with which it is pretended that astronomical observations were then made: but it is very certain that, if such a machine existed in that country, it was at a much later age than that of Yao, when the people were only beginning to form written characters and when, consequently, they cannot be supposed to have constructed such instruments as armillary spheres for the purpose of determining the places of stars.

The possibility that the ancient Chinese may have acquired some knowledge of the retrogradation of the equinoctial or solstitial points has been inferred from the positions assigned to the winter solstice by means of two recorded observations; of

which the first was made about 1100, and the other, about 500 years before Christ: the difference between the two positions is alleged to be nearly 9 degrees, which ought, certainly, to have shewn that the solstice had retrograded to that extent in the interval; but as no notice occurs of such change of place in any of the writings of that people, before the commencement of our era, we can hardly avoid concluding that the difference, if at all regarded, was ascribed to errors of observation.

It is related in the histories of China that, at a period corresponding to the year 164 of our era, certain foreigners came to that country from the west; and from this time we begin to find, in its astronomy, facts which indicate that the science had made considerable advances in the career of improvement; it is consequently more than probable that the discoveries of the Chaldeans and Greeks then found their way into the celestial empire, through the medium of the Hindus, or otherwise, and this may account for the points of resemblance observed in the astronomies of the Chinese and Europeans. About 370 years before the above time, the writings of the ancient philosophers of China had been destroyed by the tyrannical Tsi-hoang-ti, as those of the Egyptians and Chaldeans afterwards were by the fanatic Omar; in both cases, from an opinion that ignorance is the mother of piety and humility, and an apprehension that the acquisition of knowledge is detrimental to the interests of religion and government: errors which have not, even yet, disappeared from the earth. But, in China, as in Egypt, an enlightened sentiment almost immediately succeeded to the previous barbarism; for, about 50 years after the destruction, a collection was made of such works as remained: and from the copies of these works, or rather from the commentaries subsequently made on them, in which it must be expected that much matter has been introduced that was not in the originals, is derived all we know of the ancient science of that remote region.

The most remarkable circumstance connected with the Chinese astronomy is the great number of eclipses which are noticed in the works of the native writers, and of which the principal are consigned in the general history of China translated by Père Mailla. The first of these is alleged to have taken place on

the morning of a new moon during autumn in the sixth year of the reign of Tchong Kong, coinciding with the year 2159 Before Christ; and it is added that the two royal astronomers whose duty it was to announce such phenomena, were put to death for having omitted to predict it. The record of so ancient a phenomenon naturally excited the attention of the Europeans; and Père Glaubil, with other missionaries who had studied the language and sciences of China, endeavoured to ascertain, by computations founded on modern tables, if the eclipse were real or not: the result of their researches is that an eclipse, at that season, occurred in the year 2155 Before Christ; and it is concluded that this was the eclipse mentioned in the history; though, if the tables are to be depended on, it was so small as to be scarcely distinguishable to any but astronomers; and, therefore, was not likely to have created any sensation among the common people, for whom, alone, such predictions were made. and it is remarked by Delambre that if we permit ourselves to deviate from the assigned date of an eclipse four years, earlier or later, we are almost sure of finding one nearly corresponding in its conditions, with that which is given: both the eclipse, therefore, and the circumstances related concerning it are, probably, fictions of the Chinese writer, and the opinion that, at the age in which it is said to have occurred, there existed an establishment for the purpose of calculating and observing the celestial phenomena cannot be considered as resting on any good foundation.

Between the above epoch and the year 776 Before Christ not a single notice of an eclipse occurs but, from that time, they follow each other at intervals of a few years, till the year 1433 of our era, when, after a blank of two hundred years, three or four other notices terminate the catalogue. All the eclipses, except two, are of the sun; ten of them, only, have the hour of the day given, and an equal number are marked total; but of the rest no particulars are related, consequently they do not admit of verification. A work ascribed to Confucius contains, however, a list of thirty six eclipses, said to have been observed between the years 776 and 480 Before Christ, of which all except five have been proved by modern calculations.

Those who deny the great antiquity of the Chinese astronomy suppose that these eclipses were not observed but simply computed, in after times, by means of the Hindu or other tables which may have been in use among the learned of the country, but it is a serious objection to this opinion that, till very lately, the native astronomers, if so they may be called, were unable to make such computations. If we leave out the first eclipse, above mentioned, there is nothing to prevent our admitting that the eclipses were really observed and registered, the Chinese have always regarded those phenomena with a sort of religious reverence, and this would naturally prompt them to preserve an account of such as they might think remarkable In the same, or even in an earlier age, the Chaldeans and other ancient people must also have made similar observations, from whence were determined those lunar periods which appear to have been known in Greece long before the time of Hipparchus, nor is there any thing improbable in the supposition that observations which required only the use of eyes or the most simple instruments were made, at the same time, by two people at the opposite extremities of the Asiatic continent. In the history of China, by Mailla, is a table of the appearances of many comets observed in that country between the years 525 Before, and 1593 After Christ, and various other phenomena, some probable and others absurd are, also, related in the same work. Several observed appulses of the planets, principally Jupiter, to certain fixed stars, subsequently to the commencement of our era, which have been collected by P. Souciet from the ancient writings of the Chinese, complete our knowledge of the observations made by that people, and sufficiently prove the great attention they must have, very early, paid to the celestial phenomena.

But it must be admitted that the Chinese have ever had few pretensions to the character of astronomers; their observations being of the rudest kind and such as could only have been subservient to the purposes of their chronology and agriculture; and no hint appearing in their works that they had, at any time, attempted to form a theory concerning the orbits of the sun, moon, and planets. The only deductions known to have been made from their observations by these over-grown infants in

science are the luni-solar cycle of 19 years, corresponding to that discovered by Meton, the length of the solar year, which they found to be less than 365¼ days, and that of the lunar year, which they made to consist of $354\frac{348}{490}$ days, this last was used by them for general purposes and it is said that they had formed, from it, a period of 4617 years which they supposed to include a certain number of revolutions without a fraction. Like the Hindus, they had also a cycle of 60 years and one of as many days; and, like almost every other people, they used the week of seven days. Sir George Staunton observes that the cycle of 60 years was used in China as an era for chronological reckoning and for regulating the luni-solar year: and he relates that each year of the cycle is distinguished by the union of two characters taken from such an arrangement of an unequal number of words, placed in opposite columns, that the same two characters cannot be found together again during 60 years. Sir George adds that "the year 1797 A. C. corresponds to the fifty-fourth year of the sixty-eighth Chinese cycle; which determines its commencement to have been in the year 2277 B. C. unless it be supposed that all the official records and public annals of the empire which bear testimony to it should have been falsified."[a] About the year 721 of our era, Y-Hong is said to have constructed tables shewing the daily motion of the sun, and to have discovered that in 84 years the planet Jupiter made $7\frac{1}{12}$ revolutions about the earth, which is nearly correct, but it does not appear that, previous to the introduction of the European astronomy, the Chinese had even observed that the movements of the planets were, alternately, direct and retrograde. At a later time, the periods of the moon's revolutions with respect to the apogeum and nodes were known, and a catalogue of fixed stars was made, which has since been lost. The ignorance of this people, with respect to the simplest operations of practical astronomy, when the Jesuit missionaries were first established in China, that is about the year 1629, is however, manifest from the following fact: on a proposal being made to intrust the foreigners with the correction of their calendar, which was then

[a] Account of Lord Macartney's Embassy to China, vol. II. chap. 7

become extremely erroneous, the native astronomers consented to the proposal of P. Verbiest that the accuracy of the European science should be put to the test by a computation of the length of the meridional shadow to be cast by a gnomon of a given height, on a given subsequent day: this exceeded the powers of the Chinese mathematicians, and the agreement between the observed length of the shadow and that which the learned fathers had determined by calculation, was immediately received by the former as a proof of the superiority of their western rivals.

The pure sciences have always been in a low state among this ancient people, the missionaries found that, before the time of Cocheou Kong, who reigned in the thirteenth century, they considered the proportion between the diameter of a circle and its circumference to be exactly as 1 to 3, and that their trigonometry was limited to a method of calculating the sides of plane right angled triangles; nor does it appear that, till they were instructed by the Europeans, they had advanced one step further, in this respect, therefore, they seem to have been far inferior to their neighbours, the Hindus. It is worthy of remark, however, that originally, like the mathematicians of Europe, they conceived the circumference of a circle to be divided into 360 degrees; but, it is said, that, as early as the year 200 Before Christ, they began to use a division of the circumference into $365\frac{1}{4}$ parts or degrees, which, evidently, must have been introduced in order that one such part might correspond to the mean daily movement of the sun; and it is added that they used a centesimal subdivision of the degrees.

Some points of resemblance are alleged to exist in the zodiacs of the Chinese and those of the Egyptians and Hindus, from whence it has been inferred that the former people adopted that division of the heavens which had, previously, been made by the others. It may be true that the sun's place in the heavens at the commencement of the year, both in India and China, was at one time the same, and coincident with the commencement of the Hindu fixed zodiac, and it is certain that all the three people divided the zodiac into twenty seven or twenty eight lunar mansions; for that the Chinese did so we learn

from Père Souciet who, in the second volume of his observations, relates that an astronomer of their nation, in the year 104 Before Christ, measured the extent of the *twenty eight constellations* by means of an instrument, probably a Clepsydra, and adds that a similar measurement was made 207 years afterward. Again, in a copy of a Chinese map of the heavens, Mr. Ramusat observed that the constellation Orion is designated by a name signifying a conqueror, which seems to correspond with the character of that hero in the Grecian fables; and that the stars in Pegasus are divided between two figures, as in the planisphere at Denderah, but all these coincidences are too uncertain, or have too much the appearance of being accidental, to afford much ground for the opinion that the representations of the celestial sphere were copied by any one of these people from either of the others, and, as it appears that the divisions of the Chinese zodiac were originally situated on the circumference of the equator, though they were, at a subsequent time, reduced to that of the ecliptic, on which circle they were placed, from the first, by all other nations, it is much more probable that the astronomers of the east and west had recourse to their imaginations, independently of each other, when they found it convenient to arrange the stars in particular groups

Some knowledge of astronomy must have existed among the inhabitants of the American continent long before that continent was, by the voyages of the Spaniards, made known to the people of Europe; and either because man, independently of instruction, is naturally led to adopt similar means for determining the seasons and the divisions of time, or that the first occupiers of that vast region brought with them the processes which they had followed in Asia, from whence they came, the practices of the Peruvians and Mexicans, as far as they went, corresponded nearly with those of the ancient people of the eastern world. According to Acosta [a] the former observed the days of the equinoxes and solstices by means of gnomons which they erected before the temples of the sun; and it is said that they divided the year (which they made to consist of 365 days) into 12 months of 30 days each, adding, like the Egyptians, five

[a] Novi orbis Historia, Lib VI. cap 3.

days at the end of the twelve months, to complete the period: the Mexicans, according to the account given by Gemelli Carreri, in the *Giro del' Mundo*, divided the 360 days into 18 months of 20 days each: they also used a cycle of 13 years, conformably to the number of their gods, and another equal to four of these, or 52 years. The eighteen months were united by threes, in the interior of a ring ornamented with hieroglyphical figures, which was discovered in the country; and Bailly very reasonably supposes that these months are subdivisions of a primary division of the year into six parts; from which it would appear that this people, at one time, like the Hindus and Arabians, made use of a period of two months or 60 days. It is worthy of remark, also, that the general mode of reckoning time, in use among the Tahitians, till they adopted the European calendar, was by the year, which consisted of 12 or 13 months, by the season or half year, and by a month of 30 days [a].

[a] Polynesian Researches, Vol. I. chap 4.

CHAPTER XVII.

THE ASTRONOMY OF EUROPE DURING THE MIDDLE AGES.

Revival of Astronomy in Europe.—The system of eccentric spheres and epicycles adopted by Purbach.—The system of homocentric spheres revived by Fra Castorius.—The force of prejudice in philosophy.—Decline of astrology.—Copernicus proposes a system founded on the movement of the earth about the sun.—Explanation of the direct and retrograde movements of the planets according to the system of Copernicus.—The threefold motion of the earth.—First use of pendulums for astronomical purposes.—Hypothesis of Copernicus concerning the variations in the positions of the equinoctial points.—The elements of the solar orbit supposed to be variable.—Method of determining the distances of the planets from the sun and earth.—Complexity of the system of Copernicus.

THE science of astronomy which may, in some respects, be said to have advanced towards perfection during the reigns of the Mohammedan princes of Cairo and Bagdad was, through the Arabians who had settled in Spain, communicated to the people of Europe; and, as the learned men of the east had founded all their improvements, on the system of Ptolemy, it was natural that the same system should form the groundwork of the astronomy introduced by them into this part of the world; in fact, we find that the treatises on this science which were then, first, composed by Europeans, consist wholly of compilations from Ptolemy, with comments upon the comments previously made by the Arabians. Such were the works of the astronomers patronised by Alphonsus, king of Castile, all of whom lived about the middle of the thirteenth century; consequently, about the time that learning was on the decline in Asia and Egypt: but these were chiefly persons of the Jewish persuasion, and their writings are disfigured by what appear to be caballistic reveries, which, among that people, then, usurped the place of true philosophy. The prince just mentioned caused to be computed a set of astronomical tables agreeably to the hypotheses of Ptolemy, and containing sundry corrections of the mean

movements of the planets, with some additional equations formed with reference to the imaginary trepidation of the equinoctial points, a doctrine to which mathematicians, at that time, tenaciously adhered though founded on data which we should now think unworthy of the least confidence. We have mentioned in what manner this pretended libration was supposed to have been proved from a comparison of observations made by Ptolemy with those ascribed to a pseudo-Hermes; and we may now remark that a like inequality in the motion of the equinoctial points was, with as little reason, inferred from a comparison of the place of Spica Virginis, according to the observations of a certain Milleus who cultivated astronomy at Rome in the reign of Trajan, and that assigned to the same star by Alphonsus after an interval of 1160 years. The former observer makes the longitude of Spica equal to $5^s\ 26° \ 15'$, and the latter, $6^s\ 13°\ 48'$ [a]: but the Alphonsines, computing backward with the supposed value of the general precession, [1 degree in 72.8 years,] determined that, if the precession had been uniform, the longitude of the star in the time of Milleus would have been $5^s\ 27°\ 52'$; and they concluded that the difference [1° 37′] was caused by a movement which the equinoctial points had made in a direction contrary to that of the general precession. In fact, however, the longitude of that star in the time of Milleus was equal to $5^s\ 27°\ 22'$, and in that of Alphonsus, $6^s\ 13°\ 30'$, the error of the former astronomer being 1° 7′ in defect, and of the latter, 18 minutes in excess; and this result will serve to shew the degrees of accuracy with which the observations must have been made.

Like some of the Arabian astronomers, Alphonsus seems to have been little satisfied with the notions then prevalent concerning the planetary systems, and is said to have observed that if the Deity had deigned to consult him at the creation of the universe he could have suggested one less complex. This charge, so improperly preferred against the Author of Nature might have been, with some appearance of justice, urged against the system-makers of his own time; who, in the attempt to

[a] Ricius de motu octavæ sphæræ.

unite the material spheres of Calippus or Aristotle with the epicycles of Apollonius and Ptolemy, had produced a clumsy machine utterly inconsistent with that simplicity which has always been conceived to be the essential quality of a work attributed to the immediate agency of the Supreme Intelligence.

The Rabbi Isaac Abensid, to whom was entrusted the formation of the Alphonsine tables, finding that the change which would result, in the places of the equinoctial points, from the law of trepidation assigned by Thebith, was not sufficient to account for the increase in the longitudes of the stars since the time of Ptolemy, made the period in which the oscillatory motion of those points was compensated, equal to 7000 years, and united this movement with that of a uniform progression in the circumference of the ecliptic, which he supposed to be completed in 49000 years; but the adoption of these numbers seems to have no other foundation than the proportion they bear to the sabbatical period of seven years, and to that of the Jubilee, which is equal to forty-nine years

The century in which the disciples of the Arabian school were cultivating astronomy in Spain was distinguished by the labours of Albertus, Bishop of Ratisbon, who composed a treatise on the sphere, and of the English mathematicians, John Halifax, or Sacro Bosco as he was called, and Roger Bacon; the first of whom executed an abridgment of the Almagest with a commentary; and the last, so celebrated for his erudition and the persecutions he underwent from the ignorance and malice of men of his own order, besides many discoveries in mechanics, chemistry and optics, was the first to shew, probably from observations made by himself, that the days of the equinoxes happened earlier, with respect to the calendar, than they did in the time of Ptolemy; and he concluded, in his *Opus Majus*, that the anticipation was equal to one day in 125 years, which is nearly correct; in the same work he notices also the error in the period of Calippus, which, he rightly observes, is equal to one day in 304 years; and from these circumstances it is evident, as Bailly has shewn, that this remarkable ecclesiastic had the merit of foreseeing the necessity of correcting the calendar three centuries before that correction was actually made.

A dark period in the history of astronomy extends from the end of the thirteenth, to the middle of the fifteenth century, when Purbach, in his *Theoricæ novæ Planetarum* which was published in 1460, proposed a return to the hypothesis of material spheres, invented by the more ancient philosophers to keep the bodies composing the solar system in their eternal paths; to this he was induced, probably, by a desire to avoid the difficulty, which then, from the attention beginning to be paid to physical subjects, seems to have been felt, in conceiving why those bodies should, without any known cause, describe in space the circumferences of imaginary circles whose centres moved also upon the circumferences of other circles equally imaginary. In the system of Purbach, as in that proposed by Albategnius and Alfraganus, the exterior and interior surfaces of the spherical shells were not concentric; between the interior surface of the outer shell and the exterior surface of the next interior shell, as between two walls, another spherical shell, bearing the planet, revolved in the manner of an epicycle, in a direction contrary to that of the deferent; and, to produce these movements, two different motive powers (anima) were supposed to act. The earth was still supposed to be the centre of the universe: the system of shells constituting the eighth sphere, or that of the fixed stars, was made to include the seven systems of spheres immediately connected with the planets, and to revolve about the earth with the diurnal motion.

The dispositions and movements of the planetary spheres may be imagined from the following explanation of the system proposed by Purbach for the lunar orbit. According to this astronomer, the moon may be supposed to be accompanied by seven chrystalline shells, or hollow spheres, constituting three deferents or principal orbs, surrounding the earth at certain distances, and two, or rather four epicycles. The exterior surface of the first orb X, [Plate IV. fig. 2,] was supposed to be concentric with the earth, E, and to coincide with the interior surface of the lower orb belonging to the system of Mercury; the centre of the interior surface of X may be supposed at C, at a certain distance from the earth: within, and concentric with this surface, were two other orbs Y and Z, the former in contact, but the

other at some distance from that surface, so that between them there was a space within which were the two concentric orbs D and F forming the first epicycle; and, in the space between these, the two G and H which constitute the second epicycle: between these last the moon herself was situated. The deferents Y and Z were supposed to revolve on a common axis passing through C perpendicularly to the plane of the moon's apparent orbit in the heavens, the epicycles, D and F, on one common axis passing through S, and G and H, on another passing through V, and these last axes remain constantly parallel to themselves, and to the first axis through C, while they revolve, respectively, round C and S, their centres of motion. A P is the line of the apsides and when the moon, by the revolution of the epicycles, is brought to A, in contact with the eccentric sphere Y, she is in the auge or apogeum of her orbit, and this sphere, being supposed to have a velocity of revolution from west to east equal to the progression of that point, was called the deferent of the auge, as if the latter had been a material point attached to the surface of the sphere. The orb X revolved from east to west about an axis passing through E perpendicularly to the plane of the ecliptic, with a velocity equal to that of the moon's node; it, therefore, caused the retrogradation of this point upon the ecliptic, and, on this account, was called the deferent of the node. The orb Z was called the deferent of the first epicycle, and this, the deferent of the second, and the diameters of these epicycles were imagined to be equal to the distances between the shells which contained them The movement of S, which was uniform about C, represented the moon's mean motion: and this was modified by the movements of V about S, and of the moon about V, so as to produce the observed first and second inequalities of the motion in longitude.

At the end of the fifteenth, or the beginning of the sixteenth century, the system of homocentric spheres ascribed to Eudoxus and Calippus was revived by Fra Castorius, with the addition of several new spheres imagined for the purpose of explaining the movements of the planets and fixed stars, which were unknown to those ancient astronomers; and, in a treatise entitled *Homocentrica*, he has explained at length their disposition and

the manner in which they perform their revolutions. The relation of these hypotheses may be tedious, and what has been long since abandoned may seem scarcely deserving of description, but, since the dawn of a brighter day of science was in that age fast approaching, we feel ourselves justified in presenting a short account of the last of the systems which may be considered as belonging to the Grecian school of astronomy.

The spheres which accompany each of the five planets are divided into two classes, each, except in the case of Mars, consisting of five spheres; these, beginning with that on the exterior, are respectively denominated circumductor, circitor, contravector, anticircitor, and second contravector. Thus Saturn, Jupiter, Venus and Mercury are, each, moved by ten spheres, but on the exterior of the system of each planet, except Saturn, is one additional sphere, for the purpose of preventing the spheres of any planet from communicating their general compounded movement to those of the next interior planet. Mars has nine spheres in all, of which that on the exterior is for the purpose last mentioned, and the remaining eight are divided into two classes, each consisting of a circumductor, a circitor, a contravector and an anticircitor. The sun has four spheres and the moon, seven. And from the combination of the general diurnal motion of the heavens with the proper movement produced in each planet by its attendant orbs, it results, according to Fra Castorius, that the real movement of the planet, as well as that which, to a spectator on the earth, it appears to have, is in the direction of a spiral curve.

For each superior planet, in the spheres of the first class, the circumductor revolves upon the axis of the ecliptic in the period of the planet's sidereal revolution about the earth; under this is the circitor, which revolves upon an axis lying in the plane of the ecliptic, in the situation of the mean line of the nodes of the apparent orbit, and whose poles are carried through its circumference in the period just mentioned: under the circitor, and upon an axis whose poles revolve about the poles of the latter sphere at certain distances from them, revolves the contravector in a contrary order, and with twice its velocity, so that the last two spheres produce a trepidation, or movement alternately direct

and retrograde, in longitude, of a point in this sphere representing the place of the planet's node, together with an alternate movement of the apparent orbit, in latitude, which alternations of motion in longitude and latitude were supposed to be completed in the time of the planet's sidereal revolution. The anticircitor follows, under the contravector, and the axis of this sphere has a movement in the same order as that of the circitor, but the revolution of the sphere on its axis is directly contrary to that of the circitor on its axis; and lastly, comes the second contravector whose office is, to form, with the anticircitor, a new movement of trepidation diminishing that of the orbit in latitude which, by the movements given to the first circitor and contravector, it seems to have been impossible to avoid making too great, without, at the same time, diminishing too much the extent of the trepidation of the node in longitude. In the spheres of the second class, for each superior planet, the first was the circumductor which revolved upon the axis of the ecliptic in the interval between two consecutive conjunctions or oppositions of the planet with the sun; under this, in the same order as before, follow the circitor and contravector, which produce a trepidation, or an alternation of the planet's motion in longitude, together with the corresponding variations of its latitude; and finally, come the anticircitor and second contravector, whose uses are, to diminish the latitude which would result from the movements of the two former spheres. The last sphere was supposed to carry the planet itself [a]: thus the first five spheres produced the direct and retrograde movements supposed to have been observed in the nodes of the planet, and those variations of the planet's motion in latitude which recur in the course of its sidereal revolution about the earth; and the last five, produced the direct and retrograde movements of the planet itself and the variations of its velocity, both in longitude and latitude, which are accomplished in the period of a revolution with respect to the sun.

The principal differences between the movements of the spheres belonging to the inferior, and those belonging to the superior planets are, that the first circumductor, in the former, is made to revolve about its axis in one year, the time in which

[a] Homocentrica, sect. 2.

the sun, the apparent centre of their elongations, revolves about the earth, and the second circumductor revolves about its axis in the interval between two inferior conjunctions of each planet; and the trepidation produced by the circitor and contravector, in the second class of spheres, extends on either side of the sun as far as the greatest elongation of the planet from that luminary [a]. Four spheres were supposed to accompany the sun, and of these, the first is placed immediately under Mars, in order that the motion of the luminary may not be affected by that of the planet; under this is a circumductor, which revolves in a year on an axis coincident with that of the ecliptic; and then follow, the circitor and contravector, by which an alternately direct and retrograde movement is produced in longitude; this movement being combined with the superior movement of the circumductor, which is constantly in direct order, produces the apparent accelerations and retardations of motion observed in the sun. The orbs which accompany the moon are stated to be seven; the first is placed immediately under the sphere of Mercury to counteract the effect produced by the spheres of that planet; the second is made to revolve on the axis of the ecliptic in a direction contrary to the order of the signs, and with a velocity equal to the retrogradation of the moon's node, the third is a circumductor which also revolves upon the axis of the ecliptic but in direct order, and accomplishes its revolution in the time of a sidereal revolution of the moon; then follow the circitor and contravector, which produce an alternately direct and retrograde movement in longitude and a motion in latitude; and, in combination with the movement of the circitor, cause the direct motion of the moon to be alternately accelerated and retarded; lastly, come the anticircitor and second contravector, whose movements diminish, as in the systems of the planets, the latitude which would result from the movements of the two former spheres [b].

The system proposed by Fra Castorius for the fixed stars, consisted of four spheres, which together constituted what was called the eighth sphere. The first, or the Primum Mobile, revolved on the axis of the equator from east to west, in 24 hours,

[a] Homocentrica, sect. 3. [b] Ibid.

and carried within it all the other spheres. The second was a circitor, whose axis of revolution was supposed to be in the line joining the mean places of the equinoctial points, and the third was a contravector whose axis of revolution was inclined to that of the last sphere at a small angle, by the contrary revolutions of these two spheres the true equinoctial points obtained a movement of trepidation, which was supposed to be completed in 3600 years, and to extend about 4 degrees on each side of their mean places. The fourth may be considered as a circumductor; its axis of revolution coincided with that of the ecliptic, and it performed a revolution from east to west in 36,000 years; thus causing the general retrogradation of the equinoctial points, which was independent of the movement of trepidation just mentioned[a].

The number of spheres required in the theory above described is sixty-seven, but the inventor proposes ten others, to improve the representation of the phenomena of the fixed stars, and two additional spheres for the sun, which would make the whole number amount to seventy-nine. The theory, however, does not seem to have long enjoyed any reputation, and Ricciolus, in his *Novum Almagestum*[b], says it was rejected by the best astronomers in his days, the distances it assigns to the different planets not agreeing with those indicated by their observed parallaxes; and the solid spheres not being compatible with the observed movements of the comets. It may be added that, in the age of which we are speaking, the apparent magnitudes of the sun and moon were known to be variable, and this circumstance is irreconcileable with the hypothesis of concentric orbs; but the inventor of a system is seldom at a loss for a prop to uphold the edifice he has raised; and Castorius supposes that the celestial spaces are filled with matter of various degrees of density, in consequence of which, when a planet passes from a rarer to a denser medium, it appears larger, from the greater refraction of the light. By a similar explanation he accounts for the various durations of the eclipses of the moon: the image of the sun, he observes, being more or less magnified, the cone of shadow cast

[a] Homocentrica, sect. 2. [b] Lib. VI. cap. 18.

by the earth is more or less thick; and hence the moon takes a longer or shorter time to pass through it.

The system of eccentric spheres which had been invented by Purbach, was adopted by his pupil Regiomontanus, and continued during the following century to be received in explanation of the cause of the celestial movements, but additions were made to it subsequently to the time of those mathematicians in order that its parts might correspond more nearly with those in the system of Ptolemy. The system thus modified was published by Magini in 1589; and it may be considered as formed directly from that of the Alexandrian astronomer by substituting material spheres for imaginary circles. Each planet was supposed to have, besides the epicycle moving between two eccentric spheres, a sphere supplying the place of an equant or circle of mean motion; and, in the solar orbit, the eccentric sphere was in like manner supposed to revolve on the surface of another, to produce the movement of the apogeum and the observed variation of eccentricity. Four spheres were given to the fixed stars as in the system of Castorius, for the purpose of explaining the phenomena they were supposed to exhibit, and the ecliptic of the Primum Mobile was considered as invariable in space, each pole of the ecliptic belonging to the next interior sphere was supposed to have a libratory motion about the nearest pole of the fixed ecliptic by means of two small spheres, of which one was a deferent and the other an epicycle, and thus was produced the variations in the obliquity of the ecliptic to the equator. Each of the equinoctial points belonging to the third sphere from the exterior, was also supposed to have a libratory motion about the corresponding point on the fixed ecliptic by means of a small deferent and epicycle, to account for what appeared to be the variations of the fixed stars in longitude and latitude; and, finally, the interior sphere was supposed to produce the mean precession in longitude. Nothing is more remarkable in the ancient astronomy than that the opinion of an alternately direct and retrograde movement of the fixed stars in longitude, and of a movement in latitude, should have so long prevailed; since it is now well known that, though such movements do exist, they are much too small to have been

detected by the instruments then in use; and, therefore, the opinion must have originated in, and have been supported during all the time on, errors of observation. Ricciolus observes, however, that the astronomers of the school of Alphonsus supposed the true motion of the sphere of the fixed stars, with respect to the equinoctial points, to be always direct, but the velocity to be variable, so that when this motion was more swift than that of the sun, it seemed to be direct; when more slow, to be retrograde. And when, from superior accuracy in the instruments, and better modes of observing, this apparent retrogradation was no longer found to exist, the opinion still prevailed that the movement of the equinoctial points was variable, though, both really and apparently, in direct order.

The systems of the universe thus "*with epicycle and eccentric scribbled o'er,*" may be considered as having prevailed from the age of Apollonius to the end of the sixteenth century; and their complexity went on increasing with time till it became, at length, so great as to render them unfit for the purpose of assisting the imagination in conceiving the motions of the heavenly bodies: the removal of the prejudice in favour of the stability of the earth and of the circular movements of planets, which had taken possession of the minds of the first astronomers, like a pleasing but noxious plant spontaneously springing up in a virgin soil, and which, nourished by a blind respect for the sentiments of the learned men of antiquity had, for centuries, been taking root, was, however, a work of too great difficulty for men in ages when freedom of thought, in philosophy and religion, was considered equally criminal. But the energies of the human mind, though liable to be occasionally subdued, are incapable of being utterly destroyed, and a happy idea, as it were by an inspiration from heaven, comes in due time to rouse the dormant powers of man; then, disregarding the beaten track, he boldly prosecutes his researches in the new found way and, for a long time, discoveries follow each other with astonishing rapidity. A revolution of this nature took place at the commencement of the seventeenth century; and, before the light of sound philosophy, vanished the erroneous notions

of the ancients concerning the system of the universe along with the idle dreams of judicial astrology.

We have shewn that an attachment to this pretended art prevailed to a great extent in the heathen world; the desire which all men feel to penetrate into futurity had rendered the practice of it profitable, and its professors had, in the hope of greater gain and credit, a motive to lay its foundations in the true science of the stars; but, as these persons sometimes presumed to interfere, by their predictions, in political matters, it was to be expected that they should occasionally render themselves obnoxious to the constituted authorities; and we find that they were frequently banished from Rome as enemies of the state. The first Christians who considered any enquiry into the hidden purposes of the Deity to be an act of impiety, entertained the utmost horror of astrology, and compelled such of their proselytes as had been addicted to it, immediately to abandon the practice of the art on pain of excommunication; but the disciples of Mohammed seem to have been subject to no such prohibition, for they devoted themselves to the study with the greatest ardour, and it would seem that all their researches in astronomy were directed only to that end: the writings of this people were the cause that the art was introduced into Europe, and, it is not wonderful that, in an age characterised by credulity and ignorance, it should be as eagerly pursued in this part of the world as it had been in the East; in fact, nearly all the astronomers of Europe, from the time of Alphonsus even to that of Copernicus and Kepler, were deeply imbued with this degrading superstition. From time to time the voice of some person more enlightened than his contemporaries was raised to shew the vanity of astrology, but the fears and hopes of man continued to support the delusion till the fallacy of some predictions to which great importance had been attached, disabused persons of superior information: from that time the popular prejudice in its favour began to abate, and gradually the art itself fell into contempt. Picus de la Mirandola was one of its first opponents but his opposition was at the time considered impious, and it was predicted that he would perish by divine justice before he

was thirty-three years of age; in fact he died at the age of thirty-two; and it is more than probable that the astrologers took effectual steps, by poisoning a dangerous enemy, that their prediction should be fulfilled.

During the 1400 years which had elapsed since the time of Ptolemy, the doctrine of the immobility of the earth was pertinaciously maintained by the astronomers of Asia and Europe and, to support the system formed upon it, in spite of its insufficiency to account for many phenomena which the numerous observations made in that time had brought to light, it was necessary to have recourse to the most extravagant hypotheses and to complicate the machinery of the heavens to such a degree as to divest it of every semblance of possibility, but while nearly all the learned in Europe were, with servile timidity, following the path of their predecessors, one man alone, in the beginning of the sixteenth century, ventured, though with cautious steps, to trace a route which appears to lead almost directly to the true system of the universe, this was Copernicus who, in 1543, published his work "*De revolutionibus orbium cœlestium*", in which the phenomena of the movements of the planets are explained on the supposition that the earth has a motion upon its axis and about the sun. We have seen that this hypothesis had suggested itself to many of the ancient philosophers, but no attempt had been, before, made to found upon it a system of astronomy, and, therefore, to this work of Copernicus we must ascribe the origin of that revolution which took place in the science when the parent idea was confirmed by the discoveries of Kepler and Newton.

It must be observed, however, that Copernicus wanted all those arguments in support of the opinion that the earth was endowed with a movement of rotation and translation, which have been drawn from discoveries made subsequently to his time; and, in reply to the objections of his contemporaries, who, from the pride which is ashamed to yield, persisted in the doctrine they had so long maintained, he could only urge the simplicity of the system and appeal to what he considered the testimony of the ancients in its favour. Thus, in the preface to his work, written when near his last moments, he deprecates the

censure of the reader for publishing a theory so contrary to that which was generally received in his time, and excuses himself on the ground that he is not the author of the idea which he takes as the basis of his system of the universe. He quotes a passage from Cicero in which it is stated that Heraclides, Ecphantus and Nicetas supposed the earth to revolve about the centre of the universe, and that Philolaus had asserted the earth to be one of the stars; and he shews that Aristotle and Plutarch have ascribed to the Pythagoreans the opinion that the earth turns about the central fire, which he supposes, erroneously as we have seen, to signify the sun. But we find that though the comparative simplicity of his system recommended it to a few men like himself who could give up, in favour of an hypothesis, what appeared to be the evidence of their senses; yet, with the generality of mankind it happened, as might be expected, that the latter outweighed every consideration drawn from perceptions of beauty or convenience; and, if we add to this, the opinion then entertained, that, to consider the earth as holding only the same rank in the universe that was occupied by the other planets, instead of regarding it as the principal object for which the sun, moon and stars were created, was to hold a doctrine directly opposed to that taught in the Scriptures, we shall not be surprised that the reasonings of Copernicus and his disciples were long in acquiring any influence over the minds of men: indeed it cannot be said that those reasonings were generally adopted till the discoveries of Galileo, in mechanical science, had disposed the learned to reflect that the movements of the planets might be regulated by the laws which influence the mutual actions of terrestrial bodies.

It must, however, be distinctly understood that the planetary system promulgated by Copernicus is very far removed from that which, at present, is distinguished by his name; which can be said to have originated only when Kepler had discovered the ellipticity of the orbits of the sun, moon and planets; and to which, indeed, it corresponds, only, in the circumstance of the earth's motion: his system, on the contrary, has many points of resemblance to that of Ptolemy, and the reasons by which he establishes the nature of the orbits are nearly the same; he lays

down, as a principle[a] that the universe must be spherical because a sphere is the most perfect, or the most capacious of figures; that the natural motion of a sphere is circular and that it expresses its form by its motion[b], he observes that the apparent inequalities of planetary movements have regular returns, which could only be the case with bodies moving in circular orbits; and he concludes that those movements must, in reality, be uniform, since no cause can be assigned for any inequality, either external or internal, with regard to bodies whose nature is so regular. The spherical form of the earth is inferred from the appearance presented by a ship as it approaches to, or recedes from a spectator on the shore: and, in a section which treats of the place of the earth, he argues that, since the motions of the planets cannot be represented by homocentric circles, and that every planet has its own centre of motion, no reason can be given why the earth rather than any one of these centres should be in the midst of the universe, also, in combating the argument which the ancients drew from the descent of heavy bodies, he observes that there is no reason to suppose this property peculiar to the earth and if, in thought, says he, we place ourselves in any other planet, even in the sun, we shall then, still, think ourselves at the centre of the celestial movements.

Ptolemy had urged in support of his opinion of the earth's immobility that, if it revolved on its axis, all the objects on its surface would, by the swiftness of the motion, be thrown from thence and dispersed in space; and, in reply to this argument, Copernicus turns it against the objector by observing[c] that the diurnal revolution of the sphere of the universe, on its axis, would be more likely to derange the situations of the heavenly bodies; adding, though it should be admitted, as the ancients supposed, that such revolution was necessary to prevent the stars from falling to the earth, yet this would only hold good of those which were at one particular distance from thence; those more distant, he observes, having greater velocity would continually recede, and the heavens would have no bounds. This argument, which is drawn with so much propriety from physical consider-

[a] De Revolutione, Lib. I. cap. 1. [b] Ibid. Lib. I. cap. 4.

[c] Ibid. Lib. I. cap. 8.

ations, is followed by a metaphysical, and, certainly, a much less satisfactory reason why bodies should remain on the surface of the earth notwithstanding its movement; for he observes that things which are natural are governed by laws contrary to those which appear in whatever is violent and opposed to the order of nature. Such a reply is much in the taste of the ancient schools, the question being left just as it was found; but, though it appears, from this observation, that the ideas of Copernicus concerning centrifugal forces were not more fixed than those of Anaxagoras, yet the Polish philosopher speaks almost the language of Newton when he says[a] that the cause why substances near the earth tend to its centre is only a natural tendency, given by the Supreme Being to all particles of matter, to unite and form globes, a tendency, he adds, by which the sun, moon and planets probably acquired the spherical form, and which did not prevent them from performing their different revolutions. The planets therefore being in motion, he infers from analogy that the earth, also, is in motion; but the supposed motion of the sun being thus transferred to the earth, the former, he observes, may be at rest; and he proceeds to shew how, on this hypothesis, the alternately direct and retrograde movements of the planets may be explained.

Let, for example, S [Plate IV. fig. 3] be the sun; A B C D, part of the earth's orbit; a b c d, part of the orbit of a superior planet, and X Y an arc of the celestial sphere. Then, if A be the place of the earth when the planet is at a, in opposition to the sun, the planet will, to a spectator on the earth, appear at A′ in the heavens; and the angular motion of an inferior planet being more rapid than that of a superior planet, when the earth is at B the planet may be supposed at b and, consequently, will appear in the heavens at B′, having, in the same time, apparently described the arc of retrogradation A′ B′. In like manner, while the earth describes B C, and the planet the corresponding arc b c, the movement in the heavens will be represented by B′ C′ which is still retrograde: but, when the earth is arrived at D and the planet at d, the apparent place of the latter will be D′; so that, in this last interval, its apparent movement will be in direct

[a] De Revolutione, Lib. I. cap. 9.

order; and, for a short time before and after the change, the planet would necessarily appear stationary with respect to the fixed stars. The apparent motion will, then, continue for a certain time, direct, after which, as might be easily shewn, it, again, becomes retrograde, and so on, alternately. And in a similar way the alternations of motion in the inferior planets may be explained.

In the system promulgated by Copernicus, the earth is supposed[a] to have a threefold movement, of which the first is the diurnal rotation on its axis, the second, the annual revolution about the sun; the third, a conical revolution of the earth's axis about an imaginary line perpendicular to the plane of the ecliptic and passing through the centre of the earth, which he considered as the vertex of the cone; and the inclination of the earth's axis to this line was supposed to be equal to the mean obliquity of the ecliptic to the equator. The rotation of the earth on its axis produced the succession of days and nights, and the conical revolution of the axis was intended, by Copernicus, to produce a constant parallelism of the earth's axis during the annual revolution, and thus, to cause the daily change of the sun's declination and the succession of seasons; for which purpose one of these conical revolutions should have been performed exactly in the time of an annual revolution of the earth about the sun; but, to account for the retrogradation of the equinoctial points, the periodical time of this conical revolution was supposed to be less than the time of an annual revolution of the earth by about 20 minutes which, in one year, would cause each of those points to move from one conjunction with a line joining the centres of the earth and sun, to the next, in just so much less time than it would have required to revolve from one conjunction with a line joining the earth and any fixed star, to the next; this renders the distance, on the trace of the ecliptic in the heavens, between the two positions of either equinoctial point, at the interval of one year, equal to the known value of the retrogradation.

Before the time of Copernicus, the means of making observations had been considerably improved; the ancients originally

[a] De Revolutione, Lib. I. cap. 11.

designated the time at which any phenomenon occurred, by the morning, evening or midnight; and the later Greek astronomers, either by a clepsydra or by a sun-dial, neither of which admitted of accurate subdivisions: but we are indebted to Regiomontanus, a friend of Purbach, for the first proposal to determine the hour of an observation by the altitude of the sun or a star, simultaneously taken; a method susceptible of great precision. A ball suspended by a string from a fixed point is said to have been early used to measure, by its vibrations, small intervals of time: but Walter of Nuremberg, a pupil of Regiomontanus, was the first who made use of clocks formed of wheel work, to which motion was given by a weight; it was not, however, till the middle of the seventeenth century, when a son of Galileo applied to such a machine, a pendulum, in order to regulate its movements, that they were rendered available as time keepers for astronomical purposes. It appears that the method of observing the places of stars had not changed between the times of Hipparchus and Copernicus, for the latter, in describing the process he employed, states that the longitude of the sun was found from the tables and, the Astrolabe being adjusted to coincide with the plane of the ecliptic, the degree on the circle representing this longitude was, by one of the Alidades, directed to the sun, the other alidade was directed to the moon and, subsequently, to the star; by which means the differences of the longitudes of the sun, moon and star were ascertained: Walter of Nuremberg had, however, previously to the time of Copernicus, recommended that the planet Venus, when visible together with the sun, should be used for the same purpose instead of the moon, in order to avoid the errors arising from the inaccuracy of the lunar tables, when the movement of the moon was determined for the interval between the times at which the alidade was directed to that luminary and to the star. The same astronomer proposed, also, to determine the places of planets by taking their angular distance from two or more stars; and, from thence, to compute, by trigonometry, their longitudes and latitudes, those of the stars being supposed to be known, a method which is now superseded by that practised in fixed observatories but, still, advantageously employed to determine the places of comets or

Ptolemy, to experience continual diminutions; and the place of the apogeum, which was, at first, thought to be fixed in the heavens was, by the like comparison of observations, suspected to be moveable, in an order alternately direct and retrograde.

The inequalities supposed to have been observed in the length of the tropical year were, by Copernicus, ascribed to four different causes, the first is the variation of the precession which, he observes, was the only one known to Ptolemy; and which is now considered insensible. The second, which he denominates the sun's annual equation, is nearly that which is now called the parallax of the earth's orbit, being the angle subtended, in the region of the fixed stars, by the semidiameter of the latter; in consequence of which the apparent motion of the sun, in a given time, if seen from the earth, is not in reality so great as the corresponding motion of the earth if seen from the sun; though the best modern observations have shewn that this angle, also, is insensible. The third is a variation in the above equation on account of the eccentricity of the orbit, by which the centre of uniform motion does not coincide with the sun; and the fourth depends on the observed movement of the sun's apogeum or, as it should now be called, the aphelion point of the earth's orbit.

The variations determined by observations at different seasons, in the equation of the sun's centre, and in the movement of the aphelion, not being found capable of explanation by the hypothesis of a simply eccentric orbit, Copernicus was reduced to the necessity of making the earth move upon an epicycle in the following manner. Let C (Plate V. fig. 1) be the centre of the ecliptic a p G, and make C S equal to the mean eccentricity, then S may represent the place of the sun: about C, as a centre, describe the circle F H E with a radius equal to half the difference of the greatest and least eccentricities; then, the centre H, of the epicycle A K P, on whose circumference the earth performs its annual revolution, in direct order, or from A towards K, is supposed to be carried slowly and in retrograde order, on the circumference of the circle E H F during that revolution; by this hypothesis A P, the line of the apsides, will have a libratory motion about a p, producing the supposed alternate movement

of the aphelion point A; the eccentricity SH will be variable, and will produce corresponding variations in the equation of the centre. Copernicus makes the ratio of SC to CE equal to that of 369 to 48, from such observations as he had reduced; his determination of the sun's parallax is the same as that of Hipparchus, but he makes the angular diameter of the sun equal to 31′ 48″ and 33′ 54″, when in apogeo and perigeo, respectively.

An important advantage obtained from the system of Copernicus was, that it afforded a means of determining the relative distances of the planets from the earth and sun, by taking the rectilinear distance between two positions of the earth as a base, at times when, by computation, any planet whose distance is required is in the same point of its orbit, and finding the angles subtended at the earth by the interval between the sun and planet and that between the planet and some fixed star. Thus, let S (Plate V. fig. 3) be the sun; s a fixed star, E and E′ places of the earth in its orbit, at two times, when a superior planet is in one and the same point P of its orbit; then p and p′ may be supposed to be the two apparent places of the planet when seen from E and E′ respectively. Imagine E s′ to be drawn parallel to E′s; then, the whole diameter of the earth's orbit being insensible in the celestial sphere, we may consider s and s′ as coincident, and the angle s′Ep as equal to sEp: but sE′p′ and sEp, or its equal, s′Ep, are the visible angular distances of the star and planet when seen from E′ and E respectively, and the difference pp′, of the arcs sp′ and sp, which measure those angles, may be considered as the measure of the angle pPp′, or EPE′, which is, therefore, known from observation: the line EE′ is known because each of the sides SE and SE′ is supposed equal to unity, and the angle ESE′ is the difference of the sun's, or of the earth's longitudes at the times of observation, which longitudes are known from the tables of the sun's motion. The difference between the sun's longitude when the earth is at E′, that is, the angle ♈ S S′, or the arc ♈ S′ in the celestial sphere, (♈ being the equinoctial point) and the planet's geocentric longitude, at the same time, which is measured by an arc intercepted between ♈ and p′, and is found from the tables, gives

the arc between S′ and p′, or the angle S E′P; and, since the angle S E′E is known, we have the angle E E′P; therefore, in the triangle E E′P we have a side and all the angles, to find E′P; and, in the triangle P E′S, we have E′P and E′S and the included angle; from whence we may find P S, the distance of the planet from the sun. The above is an outline of the method by which Copernicus may have found these distances; it being understood that all the necessary corrections have been made, to reduce the angular distances of the planet from the star, to the plane of the ecliptic, in which the longitudes are computed.

In the theory of the planets, Copernicus supposed those bodies to revolve about the sun, as we have said, and he proposed two hypotheses concerning the manner of their revolutions; in the first, a homocentric, or circle described about the sun as a centre, carried an epicycle which was surmounted by another, and both epicycles had equal movements but in opposite directions. In the second, a single epicycle, as M M′ (Plate V. fig. 1) was carried on an eccentric circle, as a G p, whose centre C was supposed to be distant from the sun S, three-fourths of the value assigned, by Ptolemy, to the eccentricity of the orbit; the semi-diameter of the epicycle was made one-fourth of the same value; and both the planet in the epicycle and the centre of the epicycle itself were supposed to revolve according to the order of the signs, with uniform motions. This hypothesis, however, was only applied to the superior planets; the eccentric circle of Venus was supposed to have no epicycle, but its centre moved on the circumference of a small circle, as in the system of Ptolemy; and the great eccentricity of Mercury rendered it necessary, in order to bring the results of theory nearer to those of observation, to employ, for this planet, the following modification of the hypothesis proposed for the orbit of the earth: let S be the place of the sun, and S C the mean eccentricity of Mercury: let E H F be a circle described about C, with a radius equal to half the difference of the greatest and least eccentricities; then the centre H, of the first epicycle A K P, is supposed to move upon the circumference of the circle F E H, and the planet itself to describe the second epicycle N N′, whose centre A, moves upon the circumference of the former epicycle.

Copernicus is the first who drew, from the limited elongations of Mercury and Venus from the sun, the conclusion that the latter was contained within the orbits of those planets.

In applying the first of the two hypotheses above mentioned to the lunar orbit, Copernicus supposes the deferent circle to be concentric with the earth; the centre of the first epicycle to turn on the circumference of this, according to the order of the signs; the centre of the second, to turn on the circumference of the first in a contrary order, and the moon herself on the circumference of the second, again according to the order of the signs. Twice in a month she was supposed to describe the circumference of the epicycle on which she moves; and when the centre of the first epicycle is in conjunction with the earth and sun, he considers the moon to be in perigeo, but when that centre is in quadrature, he supposes her to be in apogeo. He makes the diameter of the moon to vary from 28′ 45″ to 37′ 33″, and the parallax, from 50′ 16″ to 65′ 44″, which values, of both elements, are much nearer the truth than those assigned by Ptolemy.

One cause assigned by Copernicus for the variations of a planet's latitude was the obliquity of its orbit to the ecliptic by which the planet, in different positions with respect to its node, is at various distances from the plane of the ecliptic, the second cause was supposed to depend upon the various distances of the planet from the earth, by which the circle of longitude intercepted between the former and the ecliptic appeared to subtend various angles at the latter; and the third was referred to an oscillation of the orbit by which its inclination was increased or diminished, and this, as in the more ancient hypothesis, was explained by supposing the mean node to revolve on the circumference of a small circle whose centre was fixed in the plane of the ecliptic.

The movement given by Copernicus to the earth served to explain the alternations of planetary motion, from direct to retrograde, and the contrary, which, in the system of Ptolemy, required a particular epicycle for each planet; the equation of the centre, in any orbit, was provided for by the eccentricity which both the ancient and modern astronomer assigned to the

deferent; and the epicycle retained by the latter was intended to account for the other variations which, up to his time, had been discovered: it does not appear, however, that Copernicus had adjusted the positions and dimensions of the circles so as to make them represent all the phenomena which had been observed in the movements of the planets and it would be useless, now, to attempt such an adjustment. The system must be admitted, notwithstanding the advantages it derived from the happy idea of placing the sun in its centre, to have been extremely complicated, principally on account of that unfortunate adherence to the ancient prejudice in favour of circular and uniform motions which prevailed to the time of Kepler. Reinhold, the friend and disciple of Copernicus, makes mention indeed of an oval figure in speaking of the orbits of the planets, and observes that it may be considered as the real orbit of Mercury, he seems, however, to have in view only the curve described by the centre of the moon's epicycle in the system of Ptolemy which, as he could not avoid remarking, is of that kind, the observation is worthy of notice in the history of astronomy, but it cannot be considered as an anticipation of the discovery, subsequently made, of the true forms of the planets' orbits.

It would seem as if Copernicus had been inclined to admit the materiality of the orbits; for, speaking of his own hypothesis, in which, as in that of Ptolemy, the centre of mean angular motion and that of constant distances are at different points in space, it is, he observes, contrary to the laws of physics that a body should revolve about two points with no material object to retain it in its place: he adds that, to enable it to do so, it would be necessary to have, attached to each planet, a spirit or intelligence which should fulfil two different conditions at the same time: and it is not improbable that Copernicus, whose notions of the principle of attraction were very vague, might have been induced to fall in with the material hypothesis rather than have recourse to the agency of spiritual beings, which some astronomers of that age had adopted from the philosophy of the Platonists. When we consider the state of the human mind in the time of Copernicus, we hardly know whether to admire most his merit in the invention of those

hypotheses by which his theory of the earth's motion was made to satisfy the observed phenomena of the heavenly bodies, or the boldness which prompted him, in defiance of the prejudices of his age, to make public a theory of which the fundamental points were, then, incapable of proof. It was not till the discovery of the spheroidal figure of the earth that a direct argument could be offered in favour of its rotation on its axis; nor, till the discovery of the velocity of light and the aberration of the stars, that the earth's annual motion could be demonstrated.

A set of astronomical tables, computed on the system of this distinguished philosopher was published in 1551, by Reinhold, and was found to be more accurate than that of Ptolemy; but it is easy to conceive that this was due not so much to the superiority of the new system over the former, as to the better data afforded by the more accurate observations which had then been made.

CHAPTER XVIII.

THE WORKS OF TYCHO BRAHE AND KEPLER.

The system of Tycho Brahe.—The moon's variation and annual equation discovered.—Erroneous ideas of Tycho Brahe concerning the distances of the planets and stars.—Opinions concerning the orbits of comets.—A new star seen.—Improved methods of observing the celestial bodies.—Correct ideas of Tycho Brahe concerning the precession.—Character of Kepler.—He discovers that, in the earth's orbit, the centres of mean motion and of mean distance are not coincident.—His manner of computing the distance of the earth from the sun.—He discovers the elliptical form of the orbit of Mars.—Relation of the areas described by the earth's radii vectores.—His manner of determining the radii vectores and the anomalies.—An imaginary relation between the distances of the planets founded on an inscription of the regular bodies within their orbits.—He discovers the relation between the distances of the planets and the times of their revolution.—His hypothesis of attraction.—The planetary motions supposed to result from the combination of two forces.—The tides ascribed to the action of the moon.—Change made by Kepler in the system of Copernicus.—His law of astronomical refraction.—The last correction of the Calendar.

It will be unnecessary to dwell long upon the system proposed by Tycho Brahe, a celebrated Danish astronomer, who was for some time contemporary with Copernicus, and lived to the end of the sixteenth century; in the latter part of which he was diligently employed, in a severe climate, in making celestial observations with large and accurate instruments, several of which were his own invention. Less happy in systematising than in observing, Tycho Brahe seems to have endeavoured to unite the hypotheses of Copernicus with those of Ptolemy, perhaps induced by the repugnance, then universally felt, at the idea of the earth's movement, and a desire to share the reputation which the Polish philosopher had recently acquired. He supposes the earth to be stationary, in space, at the common centre of the orbits of the sun and moon; but he considers the sun to be the moveable common centre of the orbits of all the other planets. In his lunar system, he modified that of Copernicus by causing

the deferent, which was still made to carry a double epicycle, to be eccentric with respect to the earth, and by this combination the inequalities of the moon's motion, which had been discovered by Ptolemy, could be represented: but the observations of Tycho Brahe led to the knowledge of a new inequality which disappears in the syzygies and quadratures, and was found to have the greatest value when the luminary is in the octants, when it was supposed to amount to 40′ 30″; this is that which is now called the moon's variation; it is proportional to twice the difference between the apparent longitudes of the moon and sun, and its maximum value is about 4 minutes less than that which was, at the first discovery, assigned to it. In order to represent it, Tycho Brahe supposed the centre of the moon's eccentric to move, in direct order, upon the circumference of a small circle with a velocity equal to the double of that with which the moon advances from the sun, the circumference of this small circle passed through the earth, with which, in the syzygies, the centre of the eccentric was supposed to coincide; while, in the quadratures, it coincided with the opposite extremity of that diameter of the small circle. The centre of the first epicycle moves upon the deferent with a velocity equal to the moon's mean motion in longitude; that of the second epicycle moves in retrograde order, with the anomalistic motion, and the moon herself moves in direct order, upon the second epicycle, with a velocity which is the double of that last mentioned: and it may be observed that when the centre of the second epicycle is in the apogeum of the first, the moon is in the perigeum of the second. Tycho Brahe, from his observations, computes that the semidiameter of the first epicycle is equal to 5800; of the second, 2900; and of the small circle at the centre of the deferent, 2174, the distance from the earth to the apogeum of the deferent being equal to one hundred thousand.

It appears also that Tycho Brahe had discovered, by comparisons of the observed with the calculated places of the moon, that another inequality existed in the motion of that luminary: he does not, however, make a separate equation for it, but introduces it into that value of the equation of time which he employs in computations relating to the moon; perhaps because,

to do otherwise, would have rendered another epicycle necessary, in the lunar system. The correction for this inequality is that which is now denominated the moon's annual equation, and its maximum value is 11′ 9″, but it is proved by Delambre that it was estimated at 4′ 30″ by the Danish astronomer. The latter represented the variations in the place of the moon's nodes, and in the inclination of her orbit, by a conical revolution of the axis of the orbit about the line of its mean position.

The sun's orbit is a simple eccentric circle whose radius he made equal to 1142 semi-diameters of the earth; but the hypotheses proposed to explain the movements of the planets are nearly the same as those of Copernicus. The system of Tycho Brahe possesses, therefore, no advantage in respect of simplicity over any of those which preceded it; and it appears to have wanted even the interest which novelty inspires, since there are obscure intimations that a planetary system identical with that of the Danish astronomer had been, before, proposed by Apollonius of Perga and, nearer to his own time, by Martianus Capella. Whoever might be the inventor, it can only be considered as a combination of truth and error, forming a link which ingeniously connects together the ancient and modern machinery invented to exhibit the celestial phenomena; for a time it enjoyed some reputation among the learned of Europe, but it has, long since, sunk into merited oblivion.

The most erroneous ideas still prevailed concerning the magnitudes and distances of the planets and, indeed, it could not be otherwise, from the impossibility of detecting the true values of the parallaxes with the instruments then in use. Tycho Brahe made the proportions between the linear diameters of the sun and earth, and the distances of the sun and moon from the latter, nearly the same as those given by Ptolemy; and, like the Arabian astronomers, he supposed that the sphere of the fixed stars was nearly contiguous to the orbit of Saturn. The axis of the earth, in the system of Copernicus, remaining parallel to itself, while it revolves about the sun, is, necessarily, directed in succession to different points in space during that revolution: but the polar distance of any fixed star not being perceptibly different in winter and summer, when the earth should be at the opposite

extremities of its orbit, Tycho Brahe draws from this fact an argument against the supposed movement of the earth; asserting that to satisfy the constancy of the polar distances, on this hypothesis, it would be necessary to suppose the fixed stars to be so remote that the diameter of the earth's orbit might be invisible if seen from thence: but to this remoteness he objects on the ground that the stars appear, to the eye, of a sensible magnitude which, against all probability, would, such being the distance, indicate that they were, in reality, so great as to fill a space equal to the orbit of the earth: the telescope has, however, removed the objection, for it shews the stars only as indivisible points; it is not necessary, therefore, to suppose them superior in magnitude to the sun; like him they may shine by their own light; and their distance from our system is actually such, that a space in their region, equal in extent to the diameter of the earth's orbit subtends from the latter no visible angle, consequently the axis of our planet will always appear directed to the same point in the heavens.

In giving a reason why the planets always move in the same paths he alleges, in the spirit of the ancient philosophy, that the circular motion is natural to the celestial bodies; but he seems to be the first astronomer who, from the movements of the comets, in space, inferred that the planetary spheres could not have a *material* existence since, as he observes, the comets evidently pervade them in various directions. It had been before supposed, by those who ranked the comets among the celestial bodies, that the former revolved about the earth in orbits situated between those of the planets; and reasons, founded on the imagined qualities of the comets themselves, were offered to explain why they should be only occasionally visible: except in this respect, it seems to have been supposed that they were subject to the laws which governed the other planets. Cornelius Gemma, who thought he perceived that the curves they described were of an oval form, imagined this appearance to be an effect of perspective arising from the planes of their orbits being seen obliquely by a spectator on the earth; and, in conformity with the ancient prejudice, he conceived that the orbit of a comet consisted of a deferent circle whose plane was coin-

cident with that of the ecliptic and of which the sun or the earth was the centre, and of an epicycle perpendicular to the plane of the deferent.

The system of Tycho Brahe, as well as that of Copernicus, admitting that the latter astronomer did not insist on the materiality of the planets' orbits, had the advantage over the more ancient systems, of being consistent with the hypothesis that the comets revolve about the sun and, consequently, allowed their disappearance to be accounted for by supposing them, when near their aphelia, to be too far distant from the earth to be visible from thence. The former astronomer assigns this reason, and he coincides, in opinion, with those who considered their orbits to be circular, but he rejects the epicycle of Gemma as unnecessary, and as inconsistent with his observations on the comet of 1577 whose movement, when in opposition to the sun, appeared to be in direct order, while, in like circumstances, the movements of all the superior planets appear to be retrograde; to account for which, the earth being supposed at rest, the epicycle was introduced. This difference, however, in the directions of the motions of planets and comets afforded the Danish astronomer what he conceived to be an argument against the hypothesis of his illustrious rival; as if it were indispensable that the apparent movements of both should be always in the same order; but these apparent movements are compounded of the proper motions of the celestial body and of the earth; and the superior planets move slower than the latter, which causes them, daily, when in opposition, to be left behind, or towards the west, on comparing their places with those of the fixed stars; whereas, if the true motion of the comet should be direct, and more rapid than that of the earth, its apparent motion would, also, with respect to the fixed stars, be in that order; which was the case with the above mentioned comet, and, that so simple an explanation should not have occurred to Tycho Brahe, may be considered as an example of the effects of prejudice in rendering the mind insensible to the most obvious reasons when they are opposed to a favourite notion. The supposition that the comets partake of the nature of planets, does not, moreover, seem to have been, then, generally admitted; for many scientific men, in,

and subsequently to this age, considered those objects only as meteors existing in the atmosphere of the earth.

In November 1572 there appeared in the constellation Cassiopeia a remarkably brilliant star, which had not before been observed, and which continued visible there till March 1574, when, after a gradual diminution of lustre, it completely vanished: this being the only change which had been known to take place in the appearance of the heavens since the revival of learning in Europe; though, about 300 years before, a new star had in like manner been for a short time seen, naturally excited great attention, and concerning its nature there were formed various opinions which, as may be conceived, betray some of the erroneous ideas then entertained with regard to the constitution of the universe. Tycho Brahe, who probably was the discoverer, not being able to ascertain that it had any sensible parallax, justly enough concluded that its place was beyond the region of the planets; but he was less fortunate, in supposing that it was produced by a condensation of the matter collected in the via lactea, in which it was situated. Vallesius supposed that it was a small star previously existing, which had, simply, become brilliant on being brought, by a revolution of the sphere, among the denser light in that portion of the heavens. Some persons thought it to be a comet without motion, and the mathematician John Dee proposed the idea that it moved alternately towards, and from the earth, in a right line, and ceased to be visible when very remote from thence.

Tycho Brahe made considerable improvements in the practice of observing the celestial bodies; he ascertained, directly, the altitudes and azimuths of stars from which, by computation, he determined their latitudes and longitudes; and, as the adjustments of instruments for the horizon and meridian are susceptible of greater accuracy than those for the plane of the ecliptic, it is evident that this method possesses an important advantage over that which was formerly used: like Walter of Nuremberg he, also, determined the relative longitudes of stars by observing the distances of each from two others whose places were known, with a large sextant which was capable of being adjusted to a plane passing through one of the known stars

and that whose position was required, and, having fixed the places of a few principal stars with respect to the equinoctial point by their distance, in longitude, from the sun, which he ascertained by means of the planet Venus, the differences of longitude, observed as above said, gave the absolute longitudes of the others. To determine the time of an observation, he took the distance of the sun, or of a star, from the meridian with an equatorial instrument; and thus obtained, at once, the horary angle of the celestial body. The Danish astronomer has the honour of being the first who applied to the observed altitudes of the sun, moon, and stars, the correction for the refraction of light: he ascribed this effect to the dense vapours of the atmosphere, merely; and, erroneously supposing that it was affected by the distance of the celestial body, he made the refraction of the light from a star less than that of the light from the sun or moon. He determined its amount, when the body is in the horizon, to be 34 minutes, which is nearly correct, but he thought it insensible at elevations greater than forty-five degrees.

To conclude our account of the labours of this celebrated astronomer, we may state that he determined the precession of the equinoxes both by the difference in the lengths of the sidereal and tropical year, and by the longitudes of certain fixed stars which he had observed and compared with the longitudes found by Copernicus, Albategnius, and Ptolemy, and he fixed its annual value at 51 seconds. He did not admit that inequality of the precession which Copernicus had adopted from the ancients, justly considering that it was due to the errors of observation. Finally, he perceived that the latitudes of stars, which Ptolemy had thought invariable, had undergone some small changes; and, having observed that the relative places of the stars remained constant, he rightly concluded those changes to be caused by a displacement of the plane of the ecliptic.

In the beginning of his career, Tycho Brahe had been stimulated in his favourite pursuit by William, the Landgrave of Hesse, who, in his own country, caused an observatory to be constructed and, occasionally, as a relaxation from the cares of

government, superintended the operations of the scientific men to whom he had given it in charge. Between this enlightened prince and the Danish astronomer a correspondence was maintained till the death of the former, which preceded that of his friend by about nine years The latter days of Tycho Brahe were embittered by persecutions, of which the causes are not well known; he was, however, compelled by the Danish Government to quit his observatory in the island of Huen, at the entrance of the Baltic Sea, where, during twenty-one years, he had been diligently employed in making those observations which were, shortly afterwards, productive of so much benefit to astronomy. After his retirement, the emperor Rodolphus II. received him kindly, in Germany, and gave him an observatory at Prague where, in 1601, he died. Fifty years after his departure from the island, the village and castle of Uraniberg, where he had resided, were completely destroyed and their situations entirely forgotten.

In Kepler we have an unrivalled example of patient industry in calculation; his was the mind particularly required in that age, when a large mass of facts had been collected, and it became necessary to compare them together in order to render them available for the improvement of astronomy. This was the task of the German mathematician, who is less distinguished by his own observations than by the unwearied assiduity with which he reduced those of his friend Tycho Brahe, it was by deductions from them that he arrived at the knowledge of the laws by which the planetary motions are regulated, and that he succeeded in overturning, not only the particular systems proposed by the ancients, but even all those ideas concerning the celestial movements which had been, for so many ages, considered as fundamental laws of nature, and whose truth it had never occurred to any one to call in question.

It has been supposed that Kepler obtained a hint of the elliptical nature of the planets' orbits from the appearance of the curve described by the apogeum of the eccentric circle, in Ptolemy's theory of the moon, or by observing that, in his planetary theory, the centre of constant distances and that of uniform angular motion have some analogy with the foci of an ellipse in

whose periphery the planet might perform its revolution, from which it is thought that it would be easy for a disciple of Copernicus to fall in with the idea that the sun occupied one of those points. Such suppositions, however, appear to have no foundation except in the imaginations of those who proposed them, and it may, with more reason, be asserted that to the energies of his own mind, chiefly, were due the discoveries which have immortalised the name of this illustrious astronomer.

The differences between the observed places of the sun, and those found, for the same times, from the tables, shewed, even in the days of Tycho Brahe, that the hypothesis of an eccentric circular orbit was not entirely conformable to nature. We have before shewn, also, that, in the system of Ptolemy, the variations of a planet's movement were considered as twofold, that the first was supposed to be caused by the eccentricity of the deferent, and the other, by the movement of the planet in the circumference of its epicycle Now Tycho Brahe had found, by a comparison of his observations with the theory, that this second inequality of motion was subject to several variations, and that, to represent them, it would be necessary to suppose the epicycle to be not always of the same magnitude, and it appeared to Kepler, to whom the former astronomer had communicated the results of his observations, that, as no physical reason could be imagined why an epicycle should experience any increase or diminution of magnitude; and as, in the theory of the superior planets, the epicycle which produced the second inequality was, in the system of Copernicus, superseded by the annual movement of the earth, the cause of the variations observed by Tycho might lie in the figure of the earth's orbit, whose periphery might not, he conceived, be every where at equal distances from the centre of uniform motion. Kepler seems to have been confirmed in this opinion by reflecting that, in the orbits of all the planets, according to the Ptolemean hypothesis, the centres of constant distances, and of uniform angular motion, are at a certain distance from each other, while, in the sun's orbit, they are coincident; a difference which appeared to him to be at variance with our notions of the harmony reigning in the works of nature, and, therefore, not likely to be founded in fact.

In order to ascertain if the earth's orbit is a circle and if its centre is coincident with that of the sun, Kepler had recourse to the registers of observations made on Mars, and found two times when the planet had the same heliocentric longitude, and when the angles of commutation, or the differences between the heliocentric longitudes of Mars and the earth, were equal but on opposite sides of a line joining the sun and planet; in which positions, relatively to each other, the three bodies are situated nearly at the end of every six years. These commutations, and the earth's annual parallaxes, or the differences between the heliocentric and geocentric places of Mars, for the same times, being known from the observations, and a line joining the sun and planet, which is the common base of the two plane triangles formed between the sun, earth and Mars, being assumed as unity, the two distances of the earth from the sun were computed. Now, had the orbit been circular and described about the sun as a centre, these two distances and the two parallaxes would have been, respectively, equal to each other; their inequality was, consequently, a proof that such were not the characters of the orbit. Kepler afterwards computed four distances of the earth from the sun in like circumstances, and their differences afforded an indication that the earth's orbit was elongated in the direction of the apsides and compressed on each side of the line joining those points, with these distances and the angles included between the lines drawn from the sun to each position of the earth, he, then, calculated the eccentricity, and the longitudes of the apsides; the former, which is the difference between the least and greatest distances of the earth from the sun, or the distance from the latter to the centre of mean distance, he found equal to 0 01539, the mean distance being unity; whereas Tycho Brahe, and the astronomers who lived before the time of Copernicus, made the interval between the earth and the centre of equal distances, or the centre of mean motions, equal to 0·036, in the solar orbit.

Kepler, next, proved the deviation of the earth's orbit from a circular form, and the error of the ancient astronomers in their estimate of its eccentricity, by computing four several distances of the earth from a point supposed to be the centre of uniform

motions; in this research, he imagined four lines to be drawn from the assumed centre of mean motion, making angles with each other equal to the differences between the mean longitudes of the earth at times when Mars had the same heliocentric longitude, and to be intersected by other lines, drawn from the place of Mars, making angles, with a line joining the planet and the centre of mean motions, equal to the annual parallaxes, or differences between the heliocentric longitudes of Mars and the earth; the four distances thus determined were found quite inconsistent with the supposition of Copernicus, that the earth's orbit was a circle described about the centre of mean motions; and, from the computed distances, the eccentricity, or distance between the centres of mean motions and distances, was found equal to 0.0153, hence it appeared that the whole eccentricity, or the interval between the sun and the centre of mean movements, (which corresponds to the interval between the earth and the centre of mean motion in the ancient hypothesis,) was bisected by the centre of mean or constant distances.

Means similar to those employed in investigating the figure of the earth's orbit were, also, put in practice by Kepler to ascertain that of the orbit of Mars; assuming, at first, that it was circular and that the sun and the centre of uniform motions were on opposite sides of the centre of mean distances [a]. Like Ptolemy he uses, in this investigation, the oppositions of the planet to the sun, in order to avoid the second inequality of motion, which then, as well as at the times of conjunction, vanishes, the geocentric and heliocentric places of the planet being coincident, or the sun, earth and planet being in one line, but he differs from the Greek astronomer, in considering the oppositions to be those of the sun and planet's true places, justly observing that then, only, can the second inequality be null. He employs four observations of Mars, which were made between the years 1587 and 1595, when the planet was rising or setting acronically, consequently when in opposition to the sun, and the differences between the observed longitudes give him the angles formed at the sun by the four places of Mars in the ecliptic. He supposes lines to be drawn from the

[a] De motibus Stellæ Martis, cap. 16.

sun making angles with each other equal to these differences of longitude, and the corresponding places of the planet are found at the intersections of these lines with the circumference of a circle supposed to be described, with any radius, about an assumed centre of constant distances. A line drawn through the assumed places of the sun and of this centre represents the line of the apsides of the planet's orbit, and Kepler investigates the angles which the four radii vectores must make with the line of the apsides in order that the four places of the planet may be in the circumference of a circle; from which he, subsequently, finds the eccentricity of the circle in terms of the planet's mean distance: the problem, however, not admitting of a direct solution, he uses a tentative process, in which, after seventy successive approximations, he arrives at the conclusion that, when the mean distance of the planet is equal to unity, the distance from the sun to the centre of mean distances is equal to 0.11332, and the whole eccentricity, or the distance from the sun to the centre of uniform motion, is equal to 0.18564. This element corresponds to that which, by Ptolemy, was made equal to 0 2; and the Alexandrian astronomer had made the former distance equal to half the latter, which is less accurate than the value found by Kepler, whose results, however, are affected by his erroneous estimates of the parallaxes both of the sun and planet. The labour of so many approximations must have been immense though, as Delambre observes, not greater than that which, at present, is undergone in computing the orbit of a comet, but it was much greater than a like operation would now be, on account of the facility afforded, in trigonometrical computations, by the use of logarithms, which, in Kepler's days, were not discovered.

This astronomer, also, computed the eccentricity of Mars by means of its observed geocentric latitudes, when nearly in the apsides, the inclination of the orbit to the ecliptic being known, and, from that, he determines the errors in the equation of the centre which, on comparing the calculated places of the planet with those found from the observations of Tycho Brahe, he finds to amount to 8 or 9 minutes of a degree: but he considers it impossible that such errors could have existed in the observations

of so careful an astronomer; hence, he concludes that the hypotheses on which the computations are founded, which were the circular form of the orbit, and the existence of a point in the line of the apsides where the angular motions are proportional to the times, are erroneous; and remarks that, "as we are indebted to the divine goodness for the gift of so accurate an observer as Tycho, we ought to be thankful for it, and endeavour to find out the errors in our suppositions."

Kepler, therefore, calculated several distances of Mars from the sun, and found, by a comparison of those near the apsides, and those near the points of mean distance, whose anomalies are 90 degrees and 270 degrees, that the form of the orbit must be that of an oval, which yet, from errors in some of the distances, he, at first, thought was larger at one end than at the other: but not being able to obtain, from the supposed figure of the orbit, such values of the equation of the centre as would satisfy the observations with which he compared the results of his calculations, particularly when the planet was near the points of mean distance, he began to despair of succeeding in the attempt to discover the true figure, when he happened to remark that the secant of an angle equal to the greatest equation of the centre, or that which corresponds to an anomaly of 90 degrees, exceeded the radius by a quantity equal to the error in his computed value of the planet's distance from the sun when in this part of its orbit; and it immediately occurred to his mind that, to obtain the true length of the radius vector, it would be only necessary to suppose the orbit of the planet to be the orthographical projection of a circle whose plane is inclined to that of the orbit in an angle equal to the greatest equation of the centre, and intersects it in the line of the apsides; for on this supposition, the radius vector which is perpendicular to that line would be less than the semi-diameter of the circle, in the same proportion as the radius is less than the secant of the inclination, but such a projection is a regular ellipse; and, on comparison, it was found that the computed distances of the planet from the sun agreed, in length, with the corresponding radii vectores in this ellipse. subsequent computations shewed that a like agreement subsisted between the lengths of the radii

found from observations and theory, in the orbits of the earth and other planets; and, from this time, the hypothesis of elliptical orbits was unhesitatingly admitted. The centre of the planetary system is placed by Kepler[a] in the common intersection of the lines of the apsides of all the planets' orbits, and he supposes this intersection to be coincident with the centre of the sun.

With the value he had found for the eccentricity of the earth's orbit, Kepler calculated the radii vectores for every degree of her anomaly; from the values of which, and the daily differences of the sun's longitude or anomaly, he proved that, when the earth is in aphelio or perihelio, its velocity is inversely proportional to the lengths of the radii, consequently, that the time of describing any small given arc, in the orbit, is proportional to the length of the radius at that point; the fact could not be ascertained with so much certainty for other points in the orbit, but Kepler had sufficient reason to believe that it was general[b]; and this fortunate confidence led him to the discovery that the elliptical areas comprehended between any two radii were proportional to the times of describing the corresponding arcs of the orbit. at first, however, he considered that if radii were drawn from the sun to every point in the earth's orbit, the sum of all those radii would be, to the time in which the earth described the annual revolution, as any part whatever of that sum, is to the corresponding time: but he, afterwards, changed the sums of the radii vectores for the areas of the elliptical sectors made up of such radii, and thus arrived at an important theorem in physical astronomy.

On the supposition that the orbit of Mars had been an eccentric circle, Kepler determined the value of the radius vector in the following manner. Let S [Plate V. fig. 2.] be the sun, C the centre of the eccentric, A P the line of the apsides and M the place of the earth or any planet, in the orbit, and let fall S T perpendicularly on M C produced: then M S is the radius vector; the angle A C M, the eccentric and mean anomaly, and the angle A S M the true anomaly. Now C T is, evidently, equal to C S.

[a] Comment. De Motibus, cap 22

[b] De Motibus Stellæ Martis, cap 60.

cos ∠ ACM, therefore MT = MC + CS . cos. ∠ ACM, and MS = {MC + CS . cos ∠ ACM} sec. ∠ CMS. But the real orbit being supposed an ellipse, as AQPR, formed by projecting a circle on a plane inclined to it in an angle equal to CM′S; if we draw MN perpendicularly to AP, intersecting the periphery of the ellipse in m, the point m may be considered as the true place of the planet, and it will be evident that, to obtain the radius vector m S, of the ellipse, the former line, MS, must be reduced in the proportion of MS to MT, that is in the proportion of radius to the cosine of the inclination, Kepler, therefore, concluded that the general expression for m S is MC + CS . cos. ∠ ACM; or, as it is now written, 1 + e cos. u, MC, which represents the semitransverse axis of the ellipse, or the mean distance of the planet, being supposed equal to unity; CS, the eccentricity, being expressed by e, and the eccentric anomaly, by u. Now the angle AS m is that which is called the true anomaly on the ellipse, and the angle ACM″, or its measure AM″, being supposed to be described by the planet, with its mean motion, in the time that the planet really describes the arc A m, is called the mean anomaly: the value of this angle or arc is given, when the time elapsed since the planet was in aphelio is known, being proportional to that time, and Kepler immediately investigated expressions shewing the relations between the mean, eccentric and true anomalies In so doing, he considered that, since the sector AM″ C is supposed to be described by the uniform motion of the radius CM″, that sector, as well as the arc AM″, is proportional to the time, also the elliptical sector A m S is proportional to the time for the reason above given; and since, from the nature of the ellipse, the areas of the sectors A m S and AMS have to each other the constant ratio of m N to MN, or of QC to M′C, the latter sector is, therefore, also proportional to the time: but the times of describing A m and AM, about S, and AM″, about C being, by supposition, equal, it follows that the areas AMS and AM″ C have the same ratio to the area of the circle that the area A m S has to that of the ellipse; and, consequently, the first two are equal to one another. Now the area AMS is equal to MC . $\frac{AM}{2}$ + CS . $\frac{MN}{2}$; or, as it would be

now expressed, $\frac{u}{2}+e\frac{\sin. u}{2}$, therefore the area A M″ C is equal to the same quantity, but it is, also, equal to M C . $\frac{A M''}{2}$; or $\frac{1}{2}$ n t, [n t being taken to represent the mean anomaly, because it is proportional to the time, t] therefore we have $nt = u + e \sin. u$. Lastly, Kepler obtained the true anomaly [$=\angle$ A S m] from the proportion m S : N S : : rad. : cos. $\angle$ A S m [$=\frac{CS+CN}{mS}$; or, equal to $\frac{CS+CM \cos \angle ACM}{CM+CS \cos. \angle ACM}$], that is, $\cos v = \frac{e+\cos. u}{1+e\cos. u}$; v being taken to represent the true anomaly. But these equations for n t, and cos. v, being transcendental, Kepler, who endeavoured to obtain the value of u and v, in terms of n t, could only do it by very tedious and indirect processes; mathematicians, have however, since, exhibited these values in infinite series [a], from which, knowing the mean anomaly, the eccentric and true anomalies may be, at once, obtained; it being understood that these elements are now supposed to commence at the perihelion, instead of the aphelion point of a planet's orbit.

The absolute distances of the planets were still imperfectly known in the time of Kepler. This astronomer divided the universe into three regions, of which the first was occupied by the sun, whose diameter he supposed to be equal to fifteen diameters of the earth; the second, which extended from the sun to the orbit of Saturn, he made two thousand times as great as the former region; and to the third, which comprehended all the space between Saturn and the sphere of the fixed stars, he gave an extent in diameter equal to sixty million times the diameter of the earth. Leaving out this last, as destitute of any foundation, we may observe that the other distances are little more than one seventh of their true values, yet the relative distances of the planets were then known; Copernicus had ascertained them with considerable precision, and Kepler informs us that he, himself, had recomputed them from the observations of Tycho Brahe. He relates, in his *Prodromus*, that, from his youth, he had been accustomed to meditate on the proportions which the distances

[a] Mecanique Celeste, Liv II. Art. 22.

of the planets from the sun bear to each other, and that he was led for a time to imagine, from a contemplation of the astrological aspects, that the distances between the planets were so regulated that, between the circles representing their orbits, there might be inscribed the sides of an equilateral triangle, of a square and so on, respectively. It is remarkable enough that this fancied law, which was found to be defective when applied to the orbits of Mars and Jupiter, gave rise, in the mind of Kepler, to the idea that, between those planets, there might be situated another, which is invisible to us only because it is too small to be seen with the naked eye: now, if the German astronomer had lived till the first of the four new planets was discovered, in that region of the heavens, he would not have failed to consider it as a confirmation of his hypothesis; and, to some persons who were living when the discovery was made, the passage in Kepler's work may have appeared as a prediction; both opinions, however, must have been overturned when it was found that, in the same region, there were three other planets; yet, if we except the vague notions ascribed to some of the ancients, to Kepler is due the honour of giving the first hint that there may be planets belonging to the solar system besides those with which we are already acquainted, and, as those four would have been for ever invisible without the invention of the telescope, we may reasonably suppose that others may be brought to our knowledge by future improvements in that valuable instrument. Conscious of the insufficiency of the law above mentioned, Kepler almost immediately abandoned it; but his passion for systematising carried him on to further researches concerning the principle on which was founded the proportional distances of the planets, and he next conceived an idea that the magnitudes of the spheres supposed to be described on the diameters of the orbits were such that, between every two of them, might be contained one of the five regular bodies, the only geometrical solids bounded by plane surfaces which are capable of touching a circumscribing sphere at all their angular points, or whose planes are, all, tangents to the surface of a sphere inscribed within them. Thus he imagines that if, about a sphere circumscribing the orbit of Mercury, a regular octahedron be described, it will be

enclosed within the orbit of Venus; if, in like manner, an icosahedron be described about the orbit of Venus, it will be contained within the earth's orbit; a dodecahedron about the latter will be contained within the orbit of Mars; a tetrahedron about the orbit of Mars will be included in that of Jupiter, and a hexahedron about this last, in that of Saturn.

The reason why the distance between Jupiter and Saturn should be determined by the inscription of a cube is supposed by Kepler to be, that the cube is the only regular solid which is generated by its base; on which account he considered it the most noble of the five and, therefore, with propriety situated between the remotest planets because, according to the notions of the ancients, the highest or most distant part of the universe is the most noble; he goes on to say that the distance between Mars and Jupiter is made to depend on the pyramid, which, in dignity, is the next lower solid; and, therefore, should occupy the next inferior place; and in a similar manner he accounted for the remaining distances. The law founded on the inscription of the regular bodies adapted itself with tolerable precision to the computed magnitudes of the planetary orbits, and rendered unnecessary the supposition that a planet existed between Mars and Jupiter, Kepler was even led, now, to conclude that there could be no more than five planets, besides the sun, supposing it necessary, in order to preserve the harmony of the universe, that the admirable proportions of the celestial orbs, to use his own expression, should be represented by those of the five regular bodies: fortunately for the hypothesis, the Georgium Sidus and the four asteroids were not, then, known to exist, but it must be owned that it bears the mark of an ingenious mind; and, while the notions of the Pythagoreans concerning number and figure were not wholly abandoned, it must have appeared far from destitute of probability. It was, as M. Bailly remarks, the mania of that age to mingle sacred things with those purely fanciful; and from this mania Kepler was not free, in his *Paralipomena*, he considers three things to be at rest in the universe; the sphere of the fixed stars, the sun, and the interval which separates him from them, and these things he compares with the Trinity; making the Father, the centre; the Son,

the surface; and the Holy Spirit, all that is contained between the centre and the surface; and these three, he observes, make one whole, which is embraced by the immensity of the Deity.

But a discovery of real importance rewarded the diligence with which this indefatigable calculator investigated the numerical relations between the distances of the planets and the times of their revolutions about the sun. In the *Harmonices Mundi* [a] he observes that he had previously discovered the movement of a planet in its orbit to be variable, and the angles subtended by the arcs daily described about the sun to be inversely proportioned to the distances of the planet from the sun; also, that he had discovered the orbits of the planets to be elliptical, and the sun, the source of motion, to be in one of the foci of the ellipse. He, moreover, states that, twenty-two years before the time at which he was writing, he had discovered, in the five regular bodies, the law determining the number and distances of the planets; and that the desire of verifying this law had induced him to consecrate a great part of his life to the study of astronomy; adding that, during the above period, he had read the *Harmonics* of Ptolemy; and it would seem as if, from that work, he had obtained hints which guided him in the enquiry concerning the supposed relations between the celestial movements and distances, and the intensities of musical sounds, for he relates that he had succeeded beyond his hopes, having found that there really existed a harmony among the movements of the planets, but not of the kind he had at first imagined. He says, it is evident from observation that the velocities of the planets, or the periodical times in which their revolutions about the sun are performed, are not in any simple ratio of the mean distances from that luminary, and, therefore, he assumes that the former are proportional to some indeterminate power of the latter; that is, supposing P and p to be the periodical times of the revolutions of any two planets, R and r their mean distances, he writes $P : p :: R^x : r^x$; and, assuming for x different values, integral and fractional, he at last found that, when x was made equal to $\frac{3}{2}$, the above proportion held good for all the planets, the values of the periodical times and distances being obtained

[a] Lib. V. Cap 3.

from the observations of Tycho Brahe; hence he concludes that the proportion between the periodical times of the revolutions of any two planets is sesquiplitate of that between the mean distances, or, the squares of the times are proportional to the cubes of the mean distances Proud of his discovery and, seemingly, conscious of the advantage which his favourite science would one day derive from it, he fixes the times when the investigation began and ended, and the former appears to have been coincident with that at which he found the law of the distances from the inscription of the regular bodies between the orbits: he relates that, from errors in his data or calculations, the proportion above exhibited appeared to be erroneous but, subsequently, returning to the enquiry with renovated vigour, the darkness was dispelled from his mind on the fifteenth day of May, in the year 1618, after seventeen years spent in comparing, and meditating on the observations of Tycho Brahe. This law having been discovered only by observations made on the six planets then known, there might have existed some doubt concerning its universality, but, soon after the death of Kepler, it received a confirmation from Vendelinus, who found it to hold good, also, between the distances and periodical times of the satellites of Jupiter; it is needless to add that it is found to exist in all the planets and satellites which the telescope has, since, shewn to belong to our system.

It is to be regretted that Kepler did not content himself with this truly great discovery; but he seems to have persisted in the search after relations between the celestial movements and the tones of sound. To us, who know so much more than Kepler could know of the physical laws of motion, the enquiry may seem puerile; and it may excite surprise that the human intellect should, almost at the same time, ascend so high and fall so low: but, perhaps, it was impossible that so zealous an enquirer into Nature should omit to prosecute his researches in every direction as far as his time or means permitted, in this instance, indeed, he was unsuccessful, because he sought for truth where it was not to be found, but we may observe that, without the perseverance which his taste for analogies inspired, astronomical science might have much longer remained destitute of one of its most

important principles. The merit of Kepler's discoveries does not seem, however, to have been fully appreciated till after his death, when the demonstrations of Newton established them as infallible laws of Nature, and procured for them the confidence of the learned, who then, were enabled, by them, to anticipate the periods of many of the celestial movements which could only have been ascertained, and even with less accuracy, by the slow process of actual observation.

The proportion which Kepler had discovered between the distances of the planets from, and the times of their revolutions about the sun shewed, sufficiently, that the velocities of those bodies, and the situations of their orbits in space were maintained by some one general principle, and we find, in his *Astronomia Nova*, that he considered this principle as an attractive power residing in the sun, and exerting an influence upon the planets in such a manner that they cannot depart from the centre of its action, he seems also to have understood that a like power, or virtue, as he calls it, exists in the earth, from whence its influence extends to the moon. He observes that every corporeal substance would remain at rest wherever situated, if beyond the influence of a similar body; he describes gravity as an affection with which material bodies are endowed, and by which they tend to unite themselves together, he compares it to the magnetic virtue, and he appears to consider that, in different bodies it is proportional to their mass, for he observes that the earth attracts a stone more than the latter attracts the earth: he adds, heavy bodies do not tend to the centre of the earth as that of the universe, but merely as that of a body like themselves; and he, from thence infers, first, that wherever the earth be placed, heavy bodies will always descend to it; and next, that if the earth be not globular, such bodies will not tend to its middle point, but to different points on different sides; from which it is evident that he must have considered the attraction to exist in every particle of terrestrial matter, and the line of direction, to coincide with that about which the lateral attractions are, in equilibrio. He shews that the attractive power becomes less in proportion as its distance from the centre of action increases; and he compares the movements produced by it, in different

planets, with those of bodies situated on the arm of a steel yard, at different distances from the fulcrum[a], but it is doubtful whether or not he was aware of the true law according to which the intensity of the force diminishes.

As any power or virtue supposed to act in right lines tending to or from the sun could not, alone, cause the planets to revolve about that luminary; and the observations of Tycho Brahe on the trajectories of comets having, as Kepler remarks, proved that the solid planetary spheres of the ancients do not exist, it was necessary to introduce an additional circumstance, in order to give a reason for those revolutions. This was imagined by Kepler to consist in a rotation of the sun on its axis, and a continual emission from it, of what he calls an *immaterial species*, which, he says, is analogous to that of light, and penetrates to the utmost limits of the universe, for the *species* itself revolving with the sun like a rapid vortex, was supposed to carry with it, in gyration, the masses of the planets, and thus, the latter were made to revolve about the sun with greater or less velocity according to the density of the effluent *species* in the regions of the several planets, or according to the various degrees of resistance which it opposed to their masses. Kepler from hence concludes[b] that the orbit of each planet must constantly lie in one and the same plane, and that this is coincident with the direction in which the planet itself is impelled by the movement of the *species* emanating from the sun, and he shews the fallacy of the opinion of Fra Castorius and others, who, it seems, had adopted a notion of the ancient Egyptians, that the orbits of the planets had, in the course of time, suffered such displacements that the movements were become directly contrary to those which they originally had. Kepler himself does not seem to be aware that, since the virtue emanating from the sun can only revolve on one axis, the orbits of all the planets ought, according to his own hypothesis, to lie in one plane, which he must have known to be not the case. The opinion of Kepler, that the sun performed a revolution on his axis, preceded the knowledge of the fact, which was, however, soon afterwards

[a] Comment. de Motibus, cap. 33. [b] Ibid. cap. 34.

established by the discovery of the spots on his surface; but he seems to have erred in his estimate of the time in which the revolution should be performed.

The emanating virtue being thus supposed to proceed in right lines in the direction of the radii of a spherical surface, an opinion naturally arose that its intensity, and consequently its effect upon a given surface, was inversely proportional to the square of the distance of that surface from the centre of radiation: but it is evident that Kepler could have no other knowledge of the effects of the solar action than that which is exhibited in the variations of the planets' movements, and of these he seems to have found it impossible to give a satisfactory explanation; he shews that the aphelion and perhelion velocities of a planet are, nearly, inversely proportional to the distances; and he observes that these effects cannot entirely depend upon the sun, because a virtue emanating from thence should follow the inverse duplicate, or triplicate, instead of the simple ratio of the distances[a]: again, in an attempt to explain the movements of the aphelia and nodes of an orbit, he offers a conjecture that some object may interpose between the sun and planet and be the proximate cause of those motions, but he, immediately afterward, allows this to be impossible, because one and the same power could not make the aphelia move in direct, and the nodes, in retrograde order. To account for the variations of a planet's movement, in its passage from the aphelion to the perihelion point, and the contrary, he supposes the sun, like the magnet, to have opposite, or as he calls them, friendly and unfriendly, poles; because they seem to be endowed with contrary properties, the unlike poles attracting, and the like poles repelling each other: thus he conceives the sun to attract the planets during one half of their revolution and repel them during the other half; and he considers the same contrariety of influence to be the cause that the axis of the earth always retains its parallelism, by which each pole of the earth is, alternately, turned towards, and from the sun, during half its annual revolution; and thus the phenomena of summer and

[a] Comment. de Motibus, cap 36

winter to be produced: an additional power, however, was supposed to act upon the poles of the earth[a], which, causing the axis continually to deviate from exact parallelism, produced the slow retrogradation of the equinoctial points.

But the idea that the planets were carried about the sun in an immaterial vortex, did not prevent Kepler from feeling the necessity of giving to each planet a particular motive force which, being combined with the force of attraction, would produce a movement in a curvilinear direction; just as, and the idea was about the same time proposed by Tartalea, the expansive force of gunpowder compounded with the action of terrestrial gravity, both of which forces act in rectilinear directions, causes a cannon ball to describe a curve through the air. And the manner in which Kepler supposed the forces to act is sufficiently manifest, from his comparison of the movements of the planets to that of a boat when forced across a river by oars, or drawn across by means of a rope made fast to the opposite shore, while it is urged in a different direction by the force of the current[b]. Simple motion, he observes, is essentially rectilineal, and is the result of an impulse which may be either external or internal with respect to the moving body: when, therefore, he adds, we see a body moving in a circle, we may conclude that, besides the attractive power, some other cause must be in operation, to turn the body from its rectilineal path, and, as this argument is applied to the celestial movements, it is evident that a great step to the knowledge of the physical laws of nature had been gained since the time when a circular motion was thought essential to the heavenly bodies. Kepler, as we have said, appears to consider the attractive principle as *immaterial*, and, agreeably to the doctrine, or at least, to the language of Plato, he designates it a soul or an animal faculty; in those days, however, both light and magnetism were thought to be immaterial, yet the laws of their action were supposed to be the same as those of the action of material bodies on each other.

The justness of Kepler's ideas concerning the action of the attractive force is evident from his remark[c] that this force alone

[a] Comment. de Motibus, cap. 57. [b] De motibus Stellæ Martis.
[c] Astronomia Nova.

would cause the planets to fall towards the sun, and the moon towards the earth, and that, by their mutual attractions, the last two would approach each other and meet in a point as far from the latter as $\frac{1}{54}$ of their actual distance, supposing both bodies to be of the same density; that is, he supposed the distance of their common centre of gravity, from each, to be inversely proportional to its mass. It was a necessary consequence of the actions exerted by the bodies of the solar system on each other, that the attractive influence of the moon should be the means of raising tides in the ocean, and the fact is distinctly asserted by Kepler, who states, in the same work, that the influence of the moon extends to the earth and, by giving the waters a tendency to rise at the point which has the moon in its zenith, causes them to flow towards the torrid zone, he observes, also, that as the virtue of the moon extends to the earth, that of the earth, from the greater magnitude of this planet, must extend beyond the moon.

The sentiments of Kepler concerning the mode in which the principle of gravitation acts, approach so nearly to those delivered, subsequently, by Newton, as to leave no doubt, even if we had not the express acknowledgement of the latter, in his letter to Dr. Halley, that he was guided by them to his own splendid discoveries; and this may be asserted without disparagement to the merit of the English philosopher, who, having demonstrated the truth of those physical laws which the German astronomer can only be said to have enunciated, may be justly considered as the conqueror of a territory to which his predecessor had merely shewn the way.

The phenomena of the direct and retrograde movements of the planets were explained by Kepler in the same manner as by Copernicus, but the discovery of the elliptical orbits rendered unnecessary the hypothesis of a particular centre of mean motions, and entirely superseded the theory of epicycles; the principal inequalities in the motions of the sun, moon, and planets were corrected by the equations of the centre; and the others, as far as they were known, by empirical equations founded on data obtained from observations. Rothman had already made an improvement in that part of the system of Copernicus which

relates to the cause of the phenomena of the seasons, by rejecting the conical movement of the earth's axis; he shewed that this was unnecessary, and that the same effects would take place if the axis were supposed to move parallel to itself during the annual revolution about the sun; the improvement was adopted by Kepler, and the latter has, also, the merit of being the first who pointed out, what is indeed a necessary consequence of his theory of attraction, that the variations of the moon's movements were caused by the action of the sun upon her; but we must look to Newton for the development of the effects resulting from the mutual perturbations exercised on each other by the different bodies composing the solar system.

Considerable inaccuracies, as might be expected, occur in the details of Kepler's theory of the universe, and many unfounded fancies disfigure its general beauty; he considers the axis of the sun's rotation to be perpendicular to the plane of a fixed, or mean, ecliptic; and he gives the name of *via regia*, or the royal road, to a great circle in the heavens which lies in this place. He supposed the plane of this circle to make a variable angle with the earth's equator, the least obliquity being 22° 30′, and the greatest, 26° 5′ 50″; and the interval between the periods at which either of these obliquities recurred was supposed to be 36,000 years; the movement of the equinoctial points, constituting the precession, he supposed to take place along the circumference of this via regia; and he thought that the true ecliptic had a libratory movement, as if each of its poles revolved in a small circle about the pole of the mean ecliptic; that is, about the axis of the sun's rotation. He makes the equator of the sun coincide with the plane of the earth's orbit, but no reason is given why it should have this position rather than any other, and all these suppositions appear to be, as Delambre observes, so many remains of ancient prejudices which even the mind of Kepler could not overcome. Three comets, which appeared in 1618, engaged the attention of all the astronomers in Europe, whose ingenuity was again severely taxed to form hypotheses concerning the nature of this class of celestial bodies. from the manner in which Kepler expresses himself it would appear that he supposed them to be generated in the

atmosphere " as fishes are in the sea;" but, in another place, he evidently considers them as partaking of the nature of planets, for he attempts, though, as may be easily conceived, without success, to determine the path of one, on the supposition that its motion was rectilinear. In the conclusion of his *Astronomia Nova* he acknowledges the possibility that, in the constitution of the universe, the state of things may be very different from that which he has supposed; and, with a modesty worthy of a true philosopher, he desires that his explanations may be admitted only till some more sublime and more fortunate genius may unveil the truth, and confirm or confute his opinions.

The phenomenon known by the name of the zodaical light, appears to have been first observed by Kepler, who, also, shewed that astronomical refraction is an effect depending wholly on the medium through which the rays of light pass before they enter the eye of the spectator, and as this medium is only the atmosphere of the earth, he considers, in opposition to the opinion maintained by Tycho Brahe, that the distance of the celestial body does not affect the value of refraction at any given altitude. It follows that this value, which he proves to be proportional to the tangent of the body's zenith distance, will be the same both for the planets and fixed stars.

This illustrious astronomer, whose labours have so much benefited the science, died in 1630, and in an age when impostors professing astrology, and flattering the vanity of the great, were honoured and enriched, he lived in poverty upon a small and ill paid pension which had been assigned to him by the Emperor of Germany.

The mathematicians of Europe had, before the end of the fifteenth century, pointed out the errors of the existing calendar; they shewed that since the days of Julius Cæsar, by whose care it had been formed, or rather, since the Council of Nice, in the year 325, had made the twenty-first day of March coincide with the arrival of the sun at the vernal equinox, the times of the equinoxes and solstices had been gradually anticipating the days of the months at which they then occurred; they shewed, also, that, since the decree for regulating the celebration of

Easter had been promulgated by the same Council, the lunar cycle employed in computing the day of the festival, from the erroneous value assigned to it, had ceased to determine the precise day appointed in the decree; which was the Sunday after the full moon coinciding with, or next following, the day of the vernal equinox. These representations, probably made from religious motives, and, rather with a view to the correct determination of the greatest festival in the Christian church than to any advantage which astronomy was to derive from the correction, at length, in the last quarter of the sixteenth century, occupied the attention of the Roman Pontiff, Gregory XIII., who engaged the learned men of his time to find out a mode of intercalation which should prevent the occurrence of the like inconveniences in future: from their labours resulted that reformation of the calendar which is now adopted in all Christian states.

We have shewn that the length of the year was, by Julius Cæsar, assumed to be equal to 365.25 days; while, in reality it is only 365.242264 days; the difference, which is equal to 0.007736 days, had, since the year 325, caused an error in the civil reckoning, amounting to above 10 days, so that the day of the equinox, which should have coincided with March 21, fell on the eleventh day of that month. The correction was easily made, and it is well known that ten days were suppressed by a brief issued at Rome in the year 1582, so that the day, before considered as the fourth of October, was called the fifteenth; then, in order to keep the vernal equinox, in future, to the 21st of March, it was regulated that the intercalated day which, according to the Julian calendar, enters in every fourth year, should be omitted in every year forming a complete hundred, except in those years which constitute complete thousands, when it was to be retained. The length of the tropical year, according to the value implied in the Gregorian calendar, as it is called, is equal to 365.2425 days; which is less than its true value, as above stated, by 0.000236 day; and this in 4240 years will produce an error of one day; but, as La Place observes[a], if

[a] Exposition du Système du Monde.

a bissextile were suppressed every 4000 years, the difference would be only 0.000014 day, and this would fall within the limits of the errors which may exist in the determination of the length of the year.

The Council of Nice, by supposing the exactness of the Metonic cycle, in which 19 solar tropical years were considered equal to 235 lunations, or synodical revolutions of the moon, must, consequently, have supposed one lunation to be equal to $\frac{19}{235}$ of a solar year; and the lunar year, or twelve such lunations, to be equal to $\frac{228}{235}$ of the former year; the difference between the two is $\frac{7}{235}$ of the solar year, which, as they considered the latter to contain $365\frac{1}{4}$ days exactly, would be equal to 10 8798 days, or nearly 11 days: hence, the epact, as it was called, or the moon's age at the end of any given year being known, it would be easy to ascertain that of any subsequent year, by the continual addition of 11 days to the original epact· thus, if a full moon should take place on the last day of any year, the epact for the next year would be 0, of the second following year, 11; of the third, 22, and of the fourth 3, thirty days being rejected: the epact for the succeeding years would be, respectively, 14, 25, 7; rejecting twenty-nine days from the last; and so on, rejecting alternately, 30 days and 29 days, because the lunation was supposed to be equal to $29\frac{1}{2}$ days, and taking care to increase the epact by unity in each bissextile year. The error arising from the excess of the solar, above the lunar year not being exactly 11 days, was corrected, at the end of every lunar cycle, on the supposition that the cycle was correct, by making the epact the same as that of the nineteenth precedent year. But nineteen solar years are equal to 6939.603016 days, and 235 lunations are equal to 6939.6881565 days: the difference between these periods is 0.08514 day, which renders the Metonic cycle erroneous to the amount of one day in about 222 years; consequently, to the amount of above 6 days in the time elapsed since the regulation was established; and the computed day of the Paschall full moon, in the sixteenth century, necessarily differed just as much from the true day. In order, therefore, to keep this full moon to its place in the calendar it was necessary to allow the above rule for the epacts, which was

before perpetual, to hold good only for one hundred years; then, on account of the omission of the bissextile in every hundredth year except that which is a complete thousand, the epact at the end of every century except the tenth, was to be diminished by one day; and, again, on account of the anticipation above mentioned, the epact was to be increased, at the end of every two hundred years, by the same quantity. Tables were computed on this system by Luilius of Verona, and were employed for the purpose of determining the time of Easter, till they were superseded by the ephemerides; in these, the times at which the phases of the moon, as well as the other phenomena of the heavens, will occur, are given with superior accuracy by means of computations from the general tables of the celestial movements, which have, since those days, been brought to vast perfection.

CHAPTER XIX.

THE FIRST TELESCOPIC DISCOVERIES IN THE HEAVENS.

The Composition of forces investigated by Galileo.—Telescopic discoveries of that philosopher.—The practice of notifying discoveries in anagrams.—Persecution of Galileo by the Italian clergy.—The system of Tycho Brahe still supported by some astronomers.—Method of determining the distances and magnitudes of the planets.—System of Bullialdus.—Its improvement by Ward.—Transit of Venus observed by Horrox.—Scepticism of Descartes in philosophy.—His hypothesis that the planets revolve in vortices.—Weakness of the theory.—Forms of orbits proposed by Cassini and La Hire.—Discoveries of Huygens and Maraldi on Saturn's ring.—Discoveries of Cassini on the rotations of the planets.—Changes in the positions of the aphelia and nodes of planets.—Variations in the mean motions of Jupiter and Saturn.

An important change was now to take place in the philosophy of nature in consequence of the discovery, made by Galileo, of the laws by which material bodies act mechanically on each other. To this great mathematician we are indebted for the theory of the composition of forces, by which is determined the resultant, or equivalent, of forces acting upon bodies in the same or different directions; to him, also, we owe the investigation of the spaces described, the times of description, and the acquired velocities of bodies moving by instantaneous impulses or by the continued action of impelling forces; and the application of the theory, to bodies falling towards the earth by that attractive power with which our planet was known to be endowed. By him, also, was discovered the isochronous motion of pendulums, which has since been of so much importance in the construction of machines for measuring time.

The knowledge man had acquired of the visible heavens, also received many important accessions from the discoveries which Galileo was enabled to make by means of the telescope, then recently invented. Except the sun and moon, not one of the

celestial bodies had hitherto been observed to have any visible form or magnitude; and it was to the eye of reason alone that those appeared to be any thing but plane surfaces: the fixed stars and planets were, alike, known only as luminous and undefined points: but, now, the view of the heavens began to excite a new interest; by the telescope the planets were found to have certain magnitudes, and some of them, to undergo variations of form, while the fixed stars appeared unchanged, or only shorn of the radiance with which they seem to be surrounded when seen by the naked eye: and hence it became obvious that the former must constitute a distinct groupe of bodies infinitely nearer the earth than the others The sun, from the spots observed on his surface, was found to revolve on its axis and, consequently, was ascertained to be globular, and the light and dark spaces on the moon were distinctly perceived to be mountains and valleys nearly resembling those features on the surface of the earth.

That an instrument should have been invented by which objects, even in the remotest depths of space, are rendered accessible to human vision, and by which terrestrial objects, faintly visible in the distance, are brought, as it were, close to the eye, must have at one time appeared miraculous, but such were the effects produced by the telescope, a tube containing a system of glass lenses, in passing through which, the rays of light coming from an object are turned from their previous directions and made to converge towards the axis, so that the rays proceeding from opposite sides of the object, and entering the eye, form there an angle many times greater than that caused merely by the refractive powers of the eye itself, while the interference of rays coming from surrounding objects is almost wholly prevented; thus is produced an augmentation of the visible magnitude of an object with as small a diminution as possible of its brilliancy, and thereby may be obtained a view of the parts of its surface which would be insensible to the unassisted sight; the object being seen in the telescope just as it would appear to a spectator without one, if situated as much nearer, as the power of the telescope exceeds that of the natural eye. This instrument, in the hands of Galileo, was the means of making more disco-

veries in the heavens than had been made during three thousand years previously; and it may be added, if we consider their importance, more than have been made since the days of that philosopher. He relates, in the *Sidereus Nuncius*, that, in the year 1610, he discovered the four moons or satellites of Jupiter, and observed, also, that these revolve about that planet as our moon revolves about the earth: a circumstance which afforded, by analogy, an argument in favour of the earth's motion about the sun; since Jupiter, a planet known to have a similar motion, was found to be attended by secondary planets which, it was easily perceived, would reflect the sun's light on the primary planet as the moon reflects it on the earth. About the same time, as we learn from his letters at the end of the work above mentioned, Galileo observed that Saturn presented a remarkable appearance, at first it was thought to be accompanied by two smaller planets, one on each side, and the discovery was so announced, but, when telescopes were constructed with superior magnifying powers, what appeared to be secondary planets were found to be portions of a vast annulus which surrounds Saturn without any where touching his surface; and this circumstance, also, contributed, though indirectly, to diminish the confidence hitherto placed in the ancient systems of astronomy, by shewing that there was yet much to learn concerning the planets, and that, to obtain a correct knowledge of the universe, there would be required a more attentive study of their visible phenomena Soon afterwards, the telescope revealed to the assiduous Florentine that Venus had phases similar to those of the moon, that, when near the sun, she was seen either in the crescent form or with a round orb, and when at her greatest elongations, her disc appeared to be semicircular, and it was observed that her change of form took place exactly in that insensible manner by which the face of the moon increases and diminishes: the agreement of these phenomena with those which would be presented by a globular body revolving about, and receiving its light from another body placed at the centre of motion, rendered it impossible to doubt that Venus revolved, periodically, about the sun, and that she was, like the moon, an opaque and globular mass, it was also evi-

dent that her orbit was less in diameter than the distance of the earth from the sun. By analogy it was immediately concluded that Mercury, whose phenomena so nearly resemble those of Venus, revolved about the sun in an orbit less extensive than that of Venus; and the opinion was, afterwards, confirmed by the discovery of his phases when instruments of greater power were brought into use.

Thus the telescope came to confirm the hypotheses of Copernicus and Kepler concerning the dispositions of the bodies composing the solar system; but a conviction of the truth of those hypotheses was not, at first, universally felt: there were still some persons who preferred the darkness of error to the light of truth, and who refused to look through a telescope lest their repose should be disturbed by the sight of any phenomena which might militate against the doctrines they had been accustomed to consider as incontrovertible: subsequently, when it was no longer possible to escape the conviction that the system of Aristotle was at variance with that of nature, there were persons whose jealousy of the new school of philosophy led them to charge its disciples with having borrowed from the Stagyrite the principle of the telescope; though the only circumstance he has related, which could be construed into a designation of such an instrument, is that the stars might be seen in the day-time by looking through a long tube, or by descending into a deep well.

The Jesuit Scheiner is supposed to have been the first who observed with a telescope that the disc of the sun was occasionally diversified with dark spots, and he appears, with several other astronomers his contemporaries, to have entertained the very natural opinion that they were planets: Galileo however, nearly at the same time, perceiving that they were of irregular forms, that the periods of their apparent passages across the sun were nearly equal, and that they appeared larger when near the centre of his disc than when near either margin, concluded that they adhered to the surface of that luminary, and that their movements were caused by its revolution about an axis; a circumstance which not only proved the globular figure of the sun, but afforded a probability, from analogy, of a like movement in the earth and the other planets, and when, in 1638, Fontana

had observed the spots on Mars, from the movements of which the revolution of that planet on its axis was discovered, additional evidence was afforded that the motions of the earth and planets were, in every respect, similar. In the last place, besides the lofty ridges casting their shadows upon the plains and into the deep cavities of the moon, he observed that, about the edge between the light and dark hemispheres, were luminous points seemingly, at first, detached from her surface, but gradually increasing in magnitude till they became connected with it; and it was obvious that such appearances could only be accounted for by supposing the points to be the summits of mountains which received the solar rays before the valleys were enlightened; hence it became impossible to doubt that the moon was of the same nature as the earth.

It was a custom prevalent in the times of which we are speaking for a person who had made any discovery in philosophy, either to conceal it entirely from the rest of mankind, or to publish a notice of it in some anagram which could only be decyphered by himself or by some one to whom he might communicate the key . and in this manner Galileo disguised his discovery of the phases of Venus and of Saturn's ring. The affectation of concealing the discoveries made in nature and science prevailed universally, also, among the ancients. The Egyptian priests, the Greek philosophers and the Druids of the North would suffer no person to enter their societies except the chosen few who were regularly initiated, to such the doctrines they maintained were divulged, while the instructions given to the bulk of the people were obscurely communicated in symbolical language. Their pride and vanity were, probably, gratified by the reverence with which they were regarded by those who believed they were in possession of knowledge beyond the attainment of the rest of mankind, or they might fear that some of their doctrines, if openly taught, would shock the prejudices of the people and expose them to persecution: but the very mystery they affected appears to have occasionally exposed them to suspicion, and the obscurity of the language in which their public communications were made is, no doubt, the cause that so many absurd opinions in philosophy have been attributed to them.

The obscure intimation contained in the anagram, by which knowledge is withheld while it seems to be imparted, was intended to secure the means of proving a priority of claim to the honour of a discovery, if it should happen that another person, subsequently, advanced any pretensions to it. In the present age, fortunately, the discoverer of a new fact in science finds that he promotes his own reputation most, by immediately making public his successful efforts to improve the intellectual condition of man, to this we owe, in a great measure, the rapid progress of discovery within the last century, and the many illustrious names which adorn the annals of modern philosophy. It is worthy of remark that the selfishness which prompted the learned of former times to conceal their acquirements was, often, its own punishment, for two, or more, persons commonly made the same discovery nearly at the same time, so that it became impossible to decide to which of them really belonged the honour of being the first in the race; and it frequently happened, that the palm was awarded to one who was, merely, known as having been the first who introduced the fact to public notice.

The pride or indiscretion of Galileo, rather than his adoption of the Copernican system, excited the enmity of the ecclesiastics of Italy who, twice, availed themselves of his philosophical opinions to cite him before the Inquisition. The work which was the ostensible cause of this persecution was a dialogue between a peripatetic and a supporter of the hypothesis of Copernicus, then considered as a heresy; in which, as may easily be imagined, the advantage was made to rest with the latter: and at the second investigation, when he was seventy years of age, in order to save his life, he was forced to abjure, as contrary to the doctrines professed by the church, the dogma of the motion of the earth: the recantation, it must be owned, was as little honourable to him that made it, as to the members of the tribunal, and to the influential men of the country, who, from ignorance or malice, compelled the aged philosopher to take that humiliating step.

Notwithstanding the light thrown on the system of the universe by the investigations of Kepler and the observations of Galileo; and though the hypotheses of Ptolemy were failing by

the evidences every day rising against them; so tenaciously does the mind hold the opinions which antiquity has consecrated; so painful is it to unlearn what it has cost much time and labour to acquire, and so mortifying to receive a new truth from the hand of a contemporary, that many years elapsed before the ancient doctrines concerning the planetary orbits were wholly abandoned, and there were still many persons who endeavoured to modify them so as to make them agree with the observed phenomena of the heavens One of these was the Danish astronomer Longomontanus, who had been a disciple of Tycho Brahe but who lived in the days of Kepler and Galileo; and, either from attachment to the sentiments of his master, or respect to the letter of the Scriptures, he refused to admit the annual movement of the earth. Insensible to the arguments drawn from the discoveries which were daily making in the heavens, he persisted in supposing the orbits of the planets to be circular, and he placed epicycle upon epicycle to account for the irregularities of their movements. In his *Astronomia Danica*, he sets out with the old doctrine that circular motions are essential to the heavenly bodies, but he admits that the planetary orbits are not material; he appears, besides, to have so far caught the spirit of his age as to rise superior to the notion that the celestial sphere turned daily about the earth, and he justly ascribes that apparent revolution to a contrary movement of the latter, on its axis.

Vindelinus, in Holland, about the year 1640, maintained that the moon's orbit was circular, but he rejected the epicycles; and, in order to account for the variations of her velocity, he had recourse to the supposition that she was endowed with a libratory motion, in her orbit, which, combined with the general direct movement, produced the acceleration and retardation alternately observed. To these we may add the Jesuit Ricciolus who, in his *Almagestum Novum*, has given an interesting description of the systems of the ancient astronomers and who, to remedy their defects, proposes to make Mercury, Venus, and Mars revolve about the sun; Jupiter, Saturn, and the sun accompanied by the three former planets, revolve about the earth. Jupiter and Saturn having satellites, he considers them as primary

planets; and the others having none, he considers them only as satellites of the sun. This strange mixture of the systems of Copernicus and Tycho Brahe seems to have been contrived, as Delambre observes, in compliance with the prejudices of the church, in that age, against the motion of the earth; for, while pretending to shew the falsity of the former, he expresses himself warmly in its favour.

Astronomy owes to the Vindelinus above mentioned a great step towards the determination of the extent of the solar system; adopting the method originally proposed by Aristarchus for computing the distance of the sun from the earth, and availing himself of the aid of the telescope, and of instruments for taking angles, better graduated than formerly, he ascertained with precision the spots situated in that diameter of the moon which is perpendicular to the ecliptic; and, probably, making choice of times, for the observations, when the moon is near her nodes, and consequently, near the ecliptic, he measured the distance between the centres of the sun and moon when the latter was dichotomised, which he could ascertain with tolerable precision by observing when the line separating the enlightened and dark hemispheres passed through those spots; and repeating the observations when the moon was on opposite sides of the sun, in order to correct the error arising from the probable refraction of light in the supposed atmosphere of the moon; he found, after all the necessary corrections were made, that the elongation of the moon from the sun was equal to 89° 45′, and, consequently, that the angle subtended at the sun, by a line joining the earth and moon, was 15 minutes, hence it was easy to determine that the distance of the sun from the earth was equal to 13752 semidiameters of the latter; this is, still, much too small a quantity, yet it was an approximation to the truth superior to any that had been before made; and, probably, as near it as an observation of that kind would permit. About the same time Hortensius, another Dutch astronomer, devised an ingenious method of measuring the angular diameters of the celestial bodies, which deserves to be mentioned: he received, successively, the images of the sun, moon, and planets, in a dark room, on a screen placed in the focus of the telescope, and

by comparison, the diameters of the sun and moon being otherwise known, he deduced the values of the diameters of the planets very near the truth, and thus the absolute magnitudes of the bodies composing the solar system became nearly known.

The strongholds of error are not given up till after many struggles, therefore it is not surprising that, among those persons whom the force of reason had compelled to abandon the falling systems of Ptolemy and Tycho Brahe, there should be some who endeavoured to reconcile the elliptical theory of Kepler with the old and favourite hypothesis of uniform and circular motions. It was no longer possible to doubt the existence of an attractive principle in the sun and earth; nor could it be denied, from the differences in the mean velocities of the different planets, that the force of the attraction was less, in those which are more remote from the sun; and there were even some persons who admitted, from a reasonable opinion that it was a virtue diffused spherically every where from a centre, that its intensity must be inversely proportional to the square of the distance of the attracted, from the attracting body: yet the variations in the movement of each planet being indicative of corresponding variations in the attractive force of the sun upon the planet, and this being thought inconsistent with the imagined simplicity of nature's operations, it was attempted to shew that the variations of motion were due to the position of the orbit, and that, for each planet, there existed a plane in which the attractive force acted with uniform intensity, and in which, consequently, the angular velocities were proportional to the times of motion. This was exactly the object of a system proposed about the middle of the seventeenth century, by Albert Curtius in Germany and Bullialdus in France, the latter astronomer, seized, like many other persons of his day, with the mania of seeking the causes of planetary motion, instead of applying himself to the task of ascertaining those motions by observation, supposed that, at the creation of the earth, the Deity projected it from the vertex of an upright cone, and caused it to descend, with a spiral movement, down its surface till it arrived at the shortest distance from the sun, from whence, being destined to

revolve perpetually about that luminary, it was obliged to re-ascend, and thus it describes an elliptical curve: a similar theory is proposed for each planet, which is supposed to revolve upon the surface of its peculiar cone.

One of the foci of the ellipse belonging to each planet is supposed to be in the axis; and if the orbit be projected orthographically on the plane of the base of the cone, the areas between the radii vectores in the ellipse being proportional to the times of describing the included arcs of the periphery, the areas and, consequently, the angles between the projected radii in the circular base, will also be proportional to the times; hence, whatever be the movement of the planet in the ellipse, the corresponding angular movements about the centre of the base will be uniform.

Guided by this property of the conic sections, Bullialdus was led to imagine that the two foci of the elliptical orbit of each planet were, respectively, the centres of uniform and of variable motions, the lower focus, which is the centre of variable motion, being occupied by the sun, as in the theory of Kepler. A like system was supposed to serve for the orbits of the earth and of all the planets, but, in the lunar orbit, the following modification was found necessary. The earth was supposed to describe, about the lower focus of the moon's elliptical orbit, the circumference of a circle, by which its distance from the upper focus, and from the centre of the ellipse, was variable; then, when the earth was, by this revolution, brought nearest to the apogeum of the orbit, the variation thereby produced in the angular velocity of the moon constituted the first inequality, or that which was found by Hipparchus to take place at the times of the syzygies; and when at the opposite extremity of the same diameter of the circle, being then at the greatest distance from the apogeum, the variation of velocity was equal to the sum of the first and second variations in the theory of Ptolemy. This movement of the earth was supposed to produce a corresponding movement of the whole cone, by which the position of the moon's orbit in space would be changed; and it was from such displacement of the cone and orbit that Bullialdus gave the name of evection to that variation of the moon's motion which takes place when the

major axis is in quadrature, and which, from the time of Ptolemy who discovered it, had been denominated the second inequality. Bullialdus, also, gave to the major axis of the lunar orbit a movement parallel to itself, and extending to a small distance on each side of the centre of the earth, in order to exhibit the cause of the moon's annual equation, which, in the theory of Tycho Brahe, was explained by a supposed libratory motion performed by the centre of the moon's epicycle.

The two foci of a planet's orbit may be considered as corresponding with the centres of the earth, and of the planet's uniform angular motion, in the Ptolemean system, the angles of the planet's mean longitude, in the hypothesis of Bullialdus, having the upper focus for their vertex, while those of the true longitude are reckoned about the lower focus, or the place of the sun: an ingenious disposition which, if it could have been made to represent the results of the planet's observed movements in other respects, would have possessed the advantage of permitting that which is called Kepler's theorem, and which, in the system of that astronomer, is of a transcendental nature, to be solved by the elementary geometry.

The planetary system of Bullialdus, which he has described in his *Astronomia Philolaica*, was adopted and simplified by his contemporary Seth Ward, Savilian professor of astronomy at Oxford; and the wild fancy, that the earth and planets had, once, moved spirally down the surface of a cone being abandoned, the system which, in its improved state, was distinguished from that of Kepler by the denomination of the simple elliptical hypothesis, enjoyed for some time a certain reputation.

Among the disciples of Bullialdus may be reckoned Horrox of Liverpool, an astronomer of great talent, and whose death, at an early age, was regretted by every friend of science; he proposed an improvement, on the lunar theory above mentioned, which consisted in making the earth always occupy the lower focus of the moon's orbit, and in giving to the centre of the ellipse a movement in the circumference of a small circle described about its mean place, by which the distance of the earth from the apsides of the orbit was made variable, and the corresponding variations in the lunar motions were more correctly ex-

hibited. The same astronomer, with his friend Crabtree of Manchester, had the good fortune to be the first persons who obtained a sight of the transit of Venus over the sun's disc: this happened on the twenty-fourth day of November, 1639, when Horrox, having caused the image of the sun to fall on a screen in a darkened room, observed the planet just within the disc, and in contact with its edge on the interior side. He has given an account of the observation in a small work entitled *Venus in Sole visu;* and, from it, he determined the sun's parallax to be equal to 14 seconds; a quantity still much too great, but giving the distance of the sun from the earth rather nearer the truth than that obtained by Vindelinus. The English astronomer, however, fell into an erroneous notion that all the planets are seen from the sun under equal angles, which he supposed to be 28 seconds; and he, consequently, inferred that the diameters of the planets increased in proportion to their distances from thence.

The systems of the universe which we have, hitherto, had to consider seem to have been proposed chiefly to serve as guides in the performance of astronomical computations, we have, now, to notice one in which an attempt is made to give an explanation, from physical causes, of the existence and disposition of the bodies composing the solar system. This was undertaken by Descartes, a philosopher who, being misled by his attachment to the mode of reasoning employed in the sciences which are purely mathematical, where, a few axioms being laid down, the properties of numbers and figures are demonstrated by a chain of argument, every succeeding link of which is connected with that which precedes it; endeavoured to employ the same mode in astronomy, on the supposition that there must necessarily be the like mutual dependence in physical subjects, and that, by commencing with a few first principles, he should be able to trace the concatenation of causes and effects in nature, and arrive at the discovery of the laws by which she acts in producing the phenomena of the universe. It may be said of this philosopher that he commences his researches with supposing that there is nothing to find, for, in his enquiry concerning the principles of human knowledge, he alleges that we may enter-

tain a doubt of the existence of every thing in nature, (from the evidence of our senses,) and that we can infer our own existence only from a consciousness that, while we doubt, we are exercising the faculty of thinking *Facile quidem supponimus nullum esse Deum, nullum cœlum, nulla corpora, non autem ideo nos qui talia cogitamus nihil esse repugnat enim, ut putemus, id quod cogitat, eo ipso tempore quo cogitat, non existere. Ac proinde hæc cognitio,* ego cogito, ergo sum, *est omnium prima et certissima, quæ cuilibet ordine philosophanti occurrat*[a].

Such scepticism was, perhaps, excusable in an age when the light of reason was beginning to shine upon the philosophical world, which had, for so many centuries, been overshadowed by the clouds of the Aristotelian doctrines, and when the guides in whom, hitherto, implicit confidence had been placed were found to fail; for then, it was natural that men should endeavour to pursue the study of nature in an entirely new direction, though it were necessary to examine and make good the ground at every step At this time a great change was taking place in the human character; the examples of Bacon, Kepler and Galileo, encouraged men of well regulated minds to bring every hypothesis to the test of observation and experiment, and indisposed them for receiving an opinion, however plausible, till it had been supported by the concurrence of nature herself; and to this mode of proceeding in physical enquiries we owe the great advances which have been made in the mixed mathematical sciences during the two centuries immediately preceding our own times. But it was not in every case that the labours of philosophers were directed to their legitimate end; and the fetters of ancient prejudices being removed, it sometimes happened, as it had happened before they were imposed, that men were tempted to form hypotheses concerning things which ought to be entirely without the range of their enquiries.

Thus Descartes, following the steps of the Epicureans, assumed that the particles of original matter were endowed with motions in every direction and that, by their collision, they acquired circular movements about an infinite number of centres; thus constituting vortices or whirlpools of matter, in the cen-

[a] Principiorum Philosophiæ, Pars I. sect. 7.

tres of which the sun and stars formed themselves. The sun was supposed to be the centre of one vast vortex within which revolved all the planets with their particular vortices; and in these last, revolved the satellites of the planets: the same circular motion which caused the planets to turn about the sun, and the satellites about their respective primaries was, also, supposed to have given the bodies of the solar system their spherical forms and to have caused their revolutions upon their axes. From the solar system Descartes extended the same idea to the limits of the universe, he supposed that the heavens were divided into three regions; that the first is the vortex of fluid matter of which the sun is the centre and which extends beyond the orbit of Saturn; the second is that of the fixed stars, each of which he, also, considered as the centre of a vast vortex like that of our planetary system; and the third is, he observes, that which will be unknown to us in this life [a].

This system of vortices seems to have been intended to supersede the intelligences, or souls, which, by Kepler and others, had been introduced as causes of the movements of the celestial bodies, and Descartes conceives that it will reconcile the two contrary opinions concerning the state of the earth with respect to rest or motion; both of which opinions, he supposes, may be true at the same time. Since, says he [b], we know that the earth is not supported by columns nor suspended by cords, but surrounded by a fluid, we may suppose it at rest though it be carried on by the movement of the heavens; as a ship which is neither carried forwards by the winds nor retained by its anchors remains at rest on the ocean, while, at the same time, the flux and reflux of the water may, insensibly, displace it with respect to the same point in space. The explanation was evidently proposed to remove the objections which, in those days, were urged against the motion of the earth, from a secret prepossession in favour of the opinions of the ancients; but the time was approaching in which such explanations ceased to be necessary, by the abandonment of the prejudices which they were intended to conciliate.

Descartes, in speaking of the circular movement produced in

[a] Prin Phil Pars III sect. 30–53. [b] Ibid, Pars III. sect 26.

a stone when it is made to revolve in a sling, expressly states, in conformity to the results of daily observation, that it continually endeavours to recede from the centre in a right line touching the arc it describes, but this centrifugal force would be a necessary consequence of the revolution of the particles of matter which constitute the vortices, and it is evident, therefore, that such vortices would speedily be annihilated by the dispersion of the matter in infinite space. in reply to an objection supposed to be urged against his system, on this account, he is reduced to the necessity of asserting that the recess of the particles from the centre of the vortex is prevented by the pressure of those beyond; which, however, instead of taking away the difficulty, can only be considered as removing it a step further off. The system seems to have been entertained but a short time among the learned, and, perhaps, it was never generally received: the movements of the planets in orbits oblique to each other though in the same vortex, and those of the comets in every direction, were convincing proofs of its insufficiency, but it fell entirely when Sir Isaac Newton proved, as will be hereafter shewn, that it was incompatible with the observed laws of planetary motion.

Since the time of Descartes, France has been distinguished as the country of many celebrated mathematicians whose labours have contributed much to shed a lustre over the nation, and bring the sciences to their present highly improved state; among these are conspicuous the four Cassinis, who, successively, filled the chair of astronomy at Paris from the middle of the seventeenth to the beginning of the nineteenth century, and had the direction of the royal observatory established there by Louis XIV. Dominicus Cassini, the first of these, was by that monarch invited from Italy in 1669 and, during a long life, for he died in 1712 at the age of eighty-seven, he was unwearied in observing the heavens with instruments which were then becoming far more perfect than they had been before. Previous to his departure from, and during a subsequent visit to his native country, he re-traced in the church of St. Petronius, at Bologna, a meridian line which had been, before, executed by Ignatius Dante, and he endeavoured, by means of that line and

an aperture made in the edifice, at the height of eighty-four feet from the pavement, to ascertain with precision the visible diameter of the sun, the obliquity of the ecliptic, and other elements of the solar orbit. The image of the sun's disc, being transmitted through the aperture and received on the pavement, was daily measured; and the variations of its magnitude, being compared with the daily movement of that luminary in longitude, shewed that the velocities varied in a different proportion from the apparent diameters; Cassini concluded, from thence, that the elliptical form of the orbit was not the only cause of the observed inequalities of the sun's movement; and, in ignorance of the effects arising from the mutual attractions of the planets, he conceived that the sun's orbit might be some curve different from, but nearly resembling an ellipse; he proposed, therefore, for it, a curve, which he denominated the Cassinoid, and which, he supposed, would cause the sun, by moving in it, to undergo variations of apparent angular velocity conformable to those determined by observation. The process above mentioned may be considered as the last effort to employ the gnomon as an instrument of observation, it was expected that, by using one of great magnitude, the results obtained would be far superior in accuracy to those afforded by the mural quadrants then constructed, but this hope was found to be fallacious from the impossibility of preventing the displacement, in the course of time, of the materials employed in the construction; and the correctness with which circular instruments have, since that time, been graduated has rendered the latter far preferable for all the purposes of practical astronomy. It may be worth while to observe, here, that La Hire, who was a contemporary of Cassini, attempted to represent the forms of the planetary orbits by circles of the higher orders, in order to explain the inequalities of the movements; he, afterwards, however, abandoned the idea; and this seems to have been the last proposition made for changing the elliptical form which had been invented by Kepler The ellipse is not, indeed, the true figure of a planet's orbit nor can any geometrical figure represent that which, within certain limits, is continually varying, but mathematicians have found it convenient to use this as a means

of making a first approximation to the momentary position of a planet, in space; and they, afterwards, correct that position by various equations which the discovery of the laws of planetary action has enabled them to determine.

The substitution of two or more lenses, of convex forms, for the single concave eye glass in the telescopes used by Galileo, had greatly improved those instruments by permitting the magnifying power to be increased in a more than twofold degree, without too much diminishing the light and field of view, and without causing too great an apparent distortion of the object For this improvement astronomers are chiefly indebted to Huygens, whose telescopes first shewed the belts, as they are called, on the surface of Jupiter, and that the objects accompanying Saturn, which were before supposed to be two small stars, really constituted an annulus surrounding the planet; for, observing the latter during about nine months, he found that those objects gradually diminished in magnitude till, in January 1656, they disappeared, so that Saturn then resembled the rest of the planets in form, but, in the following October, the accompaniment returned and the planet appeared as at first: there could, therefore, be no doubt of the nature of the objects, and Huygens concluded that the ring was an opaque substance reflecting the light of the sun; he also concluded that its plane was inclined to the orbit of Saturn, and he assigned two causes for its disappearance, which are that the plane of the ring, regularly changing its position, occasionally passes through the earth, and occasionally, through the sun; in the first case, the edge, only, is presented to us and, in the other, the edge, only, is enlightened by the sun; consequently, in both cases, as the thickness of the ring subtends an angle which is then insensible, the ring is necessarily invisible to a spectator on the earth. Since that time, however, the powerful telescopes of the late Sir William Herschell, have permitted the ring to be seen in all situations. Maraldi, a nephew of Dominicus Cassini, also a diligent observer of the heavens, afterwards remarked that the ring remains invisible from the time that the plane of the ring passes through the earth, till it passes so far above or below the plane of the earth's orbit that the sun's light upon the former plane becomes

great enough to render it visible; and that it remains invisible while the plane of the ring lies between the earth and the sun, because, then, the dark side is turned towards us. The same Cassini discovered that the ring is divided by a dark elliptical line into two parts which are concentric with each other, but of unequal brilliancy, and he first observed the lines, or belts, which are commonly seen on the surface of the planet Jaques Cassini, his son, remarking that the disappearance and re-appearance of the two sides of the ring do not take place, respectively, after equal intervals of time, concluded that the whole surface of the ring is not exactly, in one plane, and M. Messier, in 1773, from the inequalities of the light as well as from the appearance of distinct luminous points when the breadth of the ring was very much diminished, concluded that the surface is considerably diversified with mountains and valleys. The shadow cast by the planet itself on the plane of the ring had been early observed; but Sir William Herschell was the first who perceived the shadow cast by the ring on the body of the planet, at a time when the edge of the former, being turned towards the earth, was itself, invisible

Huygens was fortunate enough to discover one of the satellites of Saturn, but, misled by the spirit of system, he rashly committed himself by asserting that there remained no more satellites to discover because their number was, then, exactly equal to the number of primary planets. Dominicus Cassini subsequently discovered that Saturn was accompanied by four other satellites; and, among the first discoveries made by Herschell with the great telescope he had constructed, was that of two more, which made the whole number equal to seven.

The phenomena of the planets were particularly attended to by Dominicus Cassini, and his discoveries contributed materially to establish the opinion that all the solar system is subject to one law of action; his observations on the spots of Mars and Jupiter enabled him to decide that they adhere to those planets, and, appearing larger when near the centre than elsewhere, it was evident that they revolve with the planets about the axes of the latter, and the times of their appearance and disappearance, and the positions of the paths they describe, shewed the periods in

which the revolutions are performed and the inclinations of the axes to the planes of the orbits. The same astronomer determined, also, the dimensions and positions of the orbits of Jupiter's satellites; and, from his observations of their movements, he was enabled to compute the times at which they appear, to the inhabitants of the earth, to become eclipsed by entering into the shadow of the planet: he foresaw the importance of these phenomena in the solution of the problem for finding the longitudes of places on the earth, but, before they could be rendered available for this purpose, a far more accurate knowledge of the movements of the satellites was required. In 1677, Cassini remarked a spot on the body of Jupiter, at a time when the fourth satellite was known to be between the earth and planet, and he observed that the spot quitted the latter at the moment the satellite became visible: it was, therefore, evident that this was the satellite itself, rendered visible only by the superior brilliancy of the planet. Now this appearance was not found to occur every time that the satellite was on the planet, but only after intervals of twelve years, and the inference drawn from the circumstance was that the satellites of Jupiter, like our moon, revolve on their axes in the times of their revolutions about the planet, by which means the same face of the satellite is turned towards the earth at the end of every revolution of Jupiter about the sun, and is rendered visible to us from the diminution of its brilliancy, caused by the spots supposed to be on its surface. The same astronomer, observing that the fifth satellite of Saturn gradually lost and recovered its brilliancy during its movement through the eastern and western parts of its orbit, respectively, inferred that the same law prevailed in the rotations of the satellites of that planet; an inference which was subsequently confirmed by Herschell. By one part of the disc of Venus appearing less bright than the rest, Cassini was enabled to follow that planet in its rotation on its axis; and he, from thence, concluded the time in which the rotation was performed, but with some hesitation because, on account of her apparent vicinity to the sun, she is not visible during a sufficient length of time. M Schroeter has, however, since, confirmed the opinion of Cassini from his observations on the returns of like appearances at

one of the cusps of that planet. Her movement of rotation was found to be directed nearly from north to south, a circumstance in which she is distinguished from the other planets, whose rotations are nearly from west to east, and which indicates a very small obliquity of her axis to the plane of her orbit. Another phenomenon observed by Dominicus Cassini was, that the disc of Jupiter is not circular but elliptical, being in a sensible degree compressed at the poles; his instruments were, however, not sufficiently good to allow him to ascertain the difference between the two diameters, but this was afterwards accomplished by Pound and Short, in England: a similar compression has been, subsequently, observed in the other planets, and that of Saturn is particularly great.

The librations of the moon had been observed before the time of Cassini and that by which we, occasionally, see an additional portion of the upper and lower edge of the disc had been rightly ascribed to the position of the spectator, who looks down upon her when she is in the horizon, and under her when she is near the meridian, but the above astronomer appears to have been the first who ascribed the libration in longitude to a difference between her velocity in the orbit and that of the rotation on her axis.

Besides numerous observations tending to the discovery of the forms of the planets and to a more correct determination of their mean movements by a comparison of the ancient with the modern places, the enquiries of astronomers were, in the same age, particularly directed to those circumstances which relate to the positions of the planetary orbits themselves, such as their obliquity to the ecliptic and the motions of their nodes and aphelia, which had been, in former times, very incorrectly ascertained. Maraldi determined, by means of an observation made in the year 300 Before Christ, the position of the ascending node of Jupiter's orbit, and comparing it with the position of the same node, observed 1934 years subsequently, he found that, in the interval, it had advanced 12½ degrees with respect to the equinoctial points; but these having, in the same time, retrograded 27 degrees, it was evident that the node must have retrograded, with respect to the fixed stars, as much as 14½ degrees. The

same astronomer, and his relative, Jacques Cassini, suspected, also, that the aphelia of the orbits of Jupiter and Saturn had, each, a progressive motion in space because, in the course of ages, they appeared to have advanced more than the equinoctial points had retrograded; but the want of precision in the observations did not allow them to conclude positively that such was the fact. The same uncertainty, then, prevailed concerning the movements of the nodes of Mercury and Venus, which La Hire and Cassini supposed to be in retrograde order.

The mean motions of the planets were, in this age, ascertained very correctly by comparisons of the actual places with those determined from the observations of Tycho Brahe and of the ancient astronomers, but Maraldi and Cassini discovered the remarkable fact, that the mean motion of Jupiter was, then, more rapid, and that of Saturn, less so than they had formerly been: this circumstance, which is, now, so well known to be caused by the mutual perturbations exercised by those planets on each other, appeared at first to be quite inexplicable: the latter astronomer, however, proposed an opinion that the effects resulted, in some manner, from the changes which take place in the positions of the orbits, in consequence of the progression of their apsides; and, with singular good fortune, he conjectured that the time would come when those effects would be of a contrary nature; the motion of Saturn becoming more rapid than that of Jupiter, and so on, alternately. La Lande, also, in the middle of the eighteenth century, ascertained from observation, that, during about thirty-five years previously, the mean motion of Saturn had experienced an abrupt acceleration; and the discovery of the cause of these inequalities of movement was, soon afterward, to follow. Several variations were, also, at this time, found to take place in the movements of Jupiter's satellites, in the inclinations of their orbits and in the positions of the apsides and nodes. The nodes of the fourth satellite were found to move in direct, instead of retrograde order, and those of the second, to have a motion which is alternately direct and retrograde.

CHAPTER XX.

THE THEORY OF GRAVITATION DEVELOPED BY NEWTON.

Huygens measures the intensity of terrestrial attraction by the vibrations of pendulums.—Dr. Hook's illustration of planetary motion.—Newton discovers that terrestrial gravity extends beyond the moon.—He demonstrates the laws of planetary motion.—Manner in which a planet describes an elliptical orbit.—Universality of the principle of attraction.—The sun and planets revolve about the centres of gravity.—The planets disturb each other's motions.—The perturbations produce movements in the apsides and nodes of an orbit.—Manner of decomposing a perturbating force.—Effects of perturbation in changing the figure of a planet's orbit.—Application of the theory of attraction to the moon.—Causes of the several inequalities in the moon's motions.—Cause of the retrogradation of the equinoctial points.—Physical cause of the tides.—Cause that the moon always presents the same face to the earth.—The comets shewn to be subject to the law of gravitation.—Objections at first urged against Newton's theory.—Newton's preference of the geometrical mode of investigating propositions.

About the middle of the seventeenth century Huygens, in Holland, discovered the laws by which a body descends and ascends along the arc of a cycloid, and his attempt to produce a movement of this nature, in the pendulum applied to machinery for the purpose of measuring time, in order to render the vibrations isochronous, is well known; but, though this ingenious project was not attended with the success at first anticipated, yet the laws of motion in a cycloid were found to be of great importance in the determination of the relations between the times of motion and the spaces passed through, by bodies descending near the earth, from the force of terrestrial attraction, and became the means of obtaining an expression for the intensity of that kind of attraction.

Galileo had proved, mathematically, that, since gravity is a force continually acting, it must cause a falling body to descend through spaces proportional to the squares of the times of descent; and attempts had been, subsequently, made to verify the proposition by letting bodies fall from the tops of buildings to the ground,

and measuring the spaces descended in given times; but the values thus found being liable to great uncertainty from the difficulty of ascertaining the time of descent accurately, Huygens put in practice the following method by which the utmost precision might be obtained. He had proved, from the properties of the cycloid, that the time of a vibration along that curve, is to the time of descending down the height, or axis, of the cycloid, as the circumference of a circle is to its diameter: now the length of the said axis, which is half the length of the pendulum, reckoned between the centres of suspension and oscillation, can be measured with great accuracy, and the time of a vibration can be ascertained very correctly by counting the number of vibrations performed in a considerable time, hence the space descended by a body in one second of time near the earth's surface is known to be equal to about $16\frac{1}{12}$ feet; and, because it can be shewn that the velocity which a body, subject to the action of a constant accelerative force, acquires at the end of a given time of motion, is such as would carry it, with uniform motion, through twice the space it has moved through, in the same time, if the accelerative force were to cease; it follows that a body near the earth would, at the end of one second of time, acquire a velocity of $32\frac{1}{6}$ feet; and this number, therefore, is taken as the measure of the force of gravity near the earth. Huygens, also, shewed that when a body revolves in the circumference of a circle there is an equilibrium between the centripetal and centrifugal forces, or those by which it, respectively, tends to approach to, and recede from the centre of motion; and he illustrates the subject by the condition of a stone revolving in a sling: observing that if the centrifugal, exceeded the centripetal force, the string would break, if it were less, the string would slacken, and the stone would come to the hand; but the particular velocity which a body must have, to enable it to revolve in a circular orbit about a centre of attraction, was not discovered till afterwards.

The unconnected ideas of Copernicus, Kepler, Galileo and Descartes, concerning physical action were, by Dr. Hook, collected and presented in one view He asserts that, in all the celestial bodies, there is a principle of attraction by which their par-

ticles tend to their respective centres; and that they attract all bodies within the sphere of their influence, with a power which is so much the greater as the latter are nearer to the former: he, therefore, concludes that the sun, moon and planets have an influence on the earth, affecting its motion; and, reciprocally, that the earth must exert an influence on them: he repeats the hypothesis of Galileo, that bodies, once put in motion, will continue to advance in rectilinear directions, unless some external power acts upon them to change their courses; and he goes so far as to remark that, by such external force, they may be made to describe circles, ellipses or some other curves: but both he and Dr. Halley seem to have attempted without success to ascertain what must be the law of attraction by which a body would be enabled to describe an orbit of any given form. Here Dr. Hook stops and, though the bringing these leading ideas together must have been a great assistance to any one who, subsequently, investigated the laws of planetary movement, yet an immense space intervened between those general notices and the creation of a theory by which the celestial phenomena were accounted for. Hook exhibited a representation of the laws of nature, in the solar system, by suspending a ball from the ceiling and, while it vibrated like a pendulum, giving it an impulse laterally, with respect to the plane of vibration, when the ball was found to describe an ellipse about a centre which was in the vertical line passing through the point of suspension: he, also, attached a second ball to the original one and, by an impulse, made it revolve about the first while this revolved about the said vertical line; and he shewed that, now, the original ball, which represented the earth, no longer described an ellipse, as before, but that a certain point between this and the other body, (the latter representing the moon,) described the ellipse, and that both balls revolved in curves about that point which, as he rightly supposed, represented the common centre of gravity of the two bodies. But the dependence of the forms of the orbits described by the revolving bodies on the law of attraction was unknown to Hooke and, to solve this problem, a mind still more comprehensive was wanting, and new aids were to be obtained from the pure sciences.

It is highly gratifying to observe that the principal nations of Europe have had their shares in the honour of advancing the cause of sound philosophy and, particularly, of astronomical science. We have seen that Germany gave birth to Copernicus and Kepler, of whom the former, with powerful arm, overthrew the barriers raised by ancient prejudices and advanced to some distance, though with cautious steps, over the uncertain ground beyond, while the latter, with unwearied labour essayed every probable path and, having found the right one, proceeded along it to the very gate of truth. We have seen Italy send forth Galileo, to whose piercing eye the forms of the planetary bodies stood revealed; and France and Holland raise up their Cassinis and Huygens to correct and extend the knowledge of the celestial movements, and open the way to the discovery of the earth's figure and the law of gravitation. But, as good patriots, we are proud that our country produced a Newton whose bright genius soared loftily over those of the greatest philosophers of his own, and of ancient times; who, bringing to bear upon the elements gradually accumulated during a long series of ages, the energies of his powerful mind, wrung from reluctant Nature the avowal of the laws by which she holds the material universe in equilibrio. Happy should we feel could we say that his, and our countrymen had followed his steps and, at least, shared with the men of other nations the honour of prosecuting his discoveries, both in pure and mixed mathematics, to the point they have since his time attained; but, with regret, we are obliged to own that the wreath which encircled the brows of Newton has been suffered to wither on his tomb, and, as if intellectual pursuits of the highest order were not the noblest objects of human life, and the duty of all who, by fortune, are placed above the condition of the labouring hind, the generous efforts of an enlightened few to re-excite the decaying flame of pure science, it has been too often attempted to repress, by the illiberal and mistaken objection that such researches are but remotely subservient to the interests of man. In the mean time our national rivals have cast our intellectual glories in the shade, and left us scarcely a hope of being able to recover the ground we have lost. May this consideration, however, only stimulate us, in future, to new

exertions; that we may become, at least, not unworthy of inheriting the renown our fathers have acquired!

Sir Isaac Newton was born in 1642 and, according to Dr Pemberton, it was in 1666, during his temporary retirement from the university on account of the plague then raging in Cambridge, that he began his inquiry into the nature of planetary attraction. Accident, then, seems to have led him to consider that, since the attractive force of the earth, by which a stone, when unsupported, descends with an accelerated motion, has less intensity on the top of a mountain than in a valley, it might extend, though with still diminished force, to the region of the moon; and might be that power by which, in conjunction with some lateral impulsive force originally given, our satellite is made to describe its particular orbit about the earth. An erroneous estimate of the magnitude of the earth prevented Newton from, immediately, discovering the identity of terrestrial gravity with that attractive force by which the moon is retained in her orbit, by leading him to the conclusion that the latter was greater by one-sixth than it ought to have been on that supposition, but when, subsequently, on occasion of a letter from Dr. Hook containing an enquiry into the nature of the line described by a body in falling from a great height, according to the laws of acceleration delivered by Galileo, taking also into consideration the diurnal movement of the earth, he was induced to renew, with more accurate data, his investigations concerning the action of the earth on the moon, he obtained demonstrative evidence of that identity. For, having obtained the dimensions of the moon's orbit and the value of the arc described by that celestial body in one day, he computed the versed sine, which is a decomposed part of the motion in the arc, and found it equal to the space through which any body in that region would descend towards the earth, in the same time, by the attraction of the latter, supposing this attraction to diminish in the inverse ratio of the square of the distance [a].

It appears to have been in the year 1683 that Newton communicated to the Royal Society certain propositions concerning

[a] Principia Mathematica, Lib. III. Prop. 4.

the motions of the planets round the sun, which form the basis of the great work above quoted, and of what has been since denominated physical astronomy. Having laid down the three well known laws of motion he shews, in a corollary to the third, that, if a body be urged by two forces in different directions, it will describe the diagonal of a parallelogram in the same time that, by the action of either force alone, in the direction of one of its sides, it would describe that side: and, in the first proposition of the first book, he demonstrates that if a body be continually attracted towards a centre and, at the beginning of its motion, it receive an impulse in some other direction, it will describe a curve line about that centre with a velocity either uniform or so varied that areas formed between the curve and the radii vectores drawn from the centre of attraction to any part of the periphery will be still proportioned to the times in which the body describes the arcs between those radii. In the seventeenth proposition, assuming that the central attracting force is inversely proportional to the square of the distance of the attracted body, he enquires what will be the path described by a body, if projected from a given point, in the direction of a given line and with a given velocity: and he proves that, according to the intensity of the projectile force, it will describe an ellipse or a parabola about the point of attraction as a focus: and, in the fifteenth, he demonstrates that, when several bodies revolve in ellipses about a centre of attraction situated in a common focus, the squares of the periodical times in which their complete revolutions are accomplished will be proportional to the cubes of the major axes of the orbits, respectively, or to the cubes of the mean distances of the bodies from that focus

The attractions of all the bodies composing the solar system being mutual, and the whole attraction of any planet towards the sun being made up of the attractive force residing in the sun, and of that in the planet itself, and both attractions being inversely proportional to the square of the distance of the sun and planet from each other, it is evident that the first two laws of Kepler are not affected by this mutual attraction, both forces acting in the same right line, and the sum of the two being still inversely proportional to the square of the distance ,

but the case is different with the third law, which cannot be said to hold good, strictly; since it supposes that, at equal distances from the sun, two planets would be equally attracted, whereas, the planets being of unequal magnitudes, or containing unequal masses of matter; at equal distances, the sum of the attractions of the sun and any one planet could not be equal to that of the attractions of the sun and any other planet, consequently the squares of the periodical times of revolution are not exactly proportioned to the cubes of the mean distances: and the correction due to this erroneous supposition enters among those which it is necessary to make, on account of the perturbations caused by the mutual attractions of the planets themselves.

Hitherto Newton considers the bodies attracting and attracted as mere points; but he shews[a] that the particles of matter composing the great bodies of the solar system are held together by an attractive power similar to that which is in action between the bodies themselves; and, considering that the attraction of the bodies is made up of the attractions of all the particles composing them, he proves[b] that, when two attracting spheres, whether they be both homogeneous, or both similar, with respect to their densities, at given distances from the centre, are situated at different distances from each other, their mutual attractions are directly proportional to the masses, and inversely proportional to the squares of the distances: and, in the eighth and ninth corollaries to the latter proposition, he shows that the propositions, before demonstrated, relative to the motion of points about the foci of the conic sections, hold good when both the central and the revolving bodies are attracting spheres. The laws which Kepler had, with so much labour, proved to exist among the bodies of the solar system, are, thus, proved to be necessary consequences of the attractive principle which resides in all the matter of the universe, and which varies in intensity according to the squares of the distances, inversely, as above assumed: and the manner in which a planetary body, subject to the action of an attractive force in the sun, and urged by an impulsive force in another direction, revolves in an ellipse about

[a] Princip. Lib. III., Prop. 7, cor. 1. [b] Ibid. Lib. I. Prop. 74 and 76.

that luminary, may be explained by supposing the impulsive force to have been, originally, greater or less than that which would be necessary to allow the revolving body to move in a circular orbit, on the supposition that the impulsive force is less, the planet, approaching continually nearer the sun by the excess of the attractive above the other force, acquires an augmentation of velocity, because, the sun's attraction being decomposed in the directions of a tangent, and of a normal to the orbit, the former part is coincident with the direction in which the impulsive force acts on the planet; but an augmentation of velocity is necessarily attended with an augmentation of the centrifugal force, and, when this becomes equal to the centripetal, or attracting force, the planet must be in perihelio; for, afterward, the former becoming greater than the latter force, the planet recedes from the sun, and that decomposed part of the centripetal force which coincides with the tangent to the orbit, acts in a direction contrary to that of the impulsive force; hence the velocity of the planet diminishes and, with it, the centrifugal and centripetal forces; and, these diminutions taking place by the same degrees as the augmentations on the opposite side of the line of the apsides, the planet is necessarily caused to return to the point from whence it set out, and the former movement is repeated. In like manner, if a secondary planet be attracted towards its primary, and be made subject to the action of an impulsive force in another direction, it is evident that this secondary may be made to revolve in an elliptical orbit about the principal planet, while the latter revolves, as above explained, about the sun; and thus is constituted a system of three bodies, like that of the sun, earth, and moon.

The proportions subsisting between the periodical times of revolution and the distances of the revolving bodies from the centre of attraction, being found to be the same for the earth and all the planets which revolve about the sun; it is evident that the sun is the common focus of attraction for these bodies, and that the power which retains the earth in its orbit is the same as that which retains the others; since, if the distances of the planets from the sun were all equal, the periodical times of revolution would be equal, and the planets would be attracted

with forces of equal intensity towards the centre of the system: but what is proved of the attracting power residing in the sun is proved, also, of that which resides in all the planets that have satellites; for, as the movements of these about their primaries are subject to the same laws as those of their primaries about the sun, it follows that the Earth, Jupiter, and Saturn, possess also an attractive power which varies in the inverse duplicate ratio of the distance, and thus the universality of the gravitating principle is established. And, as the attractions of the earth and planets are found to extend to their respective satellites, it cannot be doubted that they extend far beyond, though with diminished force; and, consequently, that the planets react on the sun and mutually attract each other; hence we conclude that they must produce perturbations in each other's motions, and that, from this cause, the observed velocities of the planets cannot be such as would result from a simple elliptical motion.

From the degree of attractive power exercised by the planets upon their satellites in producing the movements observed in the latter, Newton was enabled, and such a discovery could not, in a former age, have been imagined, to determine the quantities of matter in, and the densities of those planets which are attended by satellites[a], the densities of the other planets, Mercury, Venus, and Mars can only be ascertained indirectly and with much uncertainty.

In consequence of the mutual attractions of the planets, it follows that the sun is not quiescent in a common focus of their orbits, Newton shews, however[b], that the common centre of gravity of the sun and planets is never distant from the centre of the sun so much as one diameter of that luminary; and, in the corollary, he asserts that this common centre of gravity is to be considered as the true centre of the solar system: he supposes it immoveable, but modern astronomers are of a different opinion, and there is reason to believe, from the variations which have been observed in the relative distances of certain fixed stars, situated in opposite parts of the heavens, that it is moving directly towards that quarter in which are the constellations

[a] Princip. Lib III. Prop. 8. cor. 2 3. [b] Ibid Lib. III. Prop. 12.

Aquila and Hercules, or that it is performing a revolution about some unknown, but immensely remote point of space.

Since the mutual attractions of the sun and planets must, necessarily, change the simplicity of the original law of movement; the planets, on this account, cannot, strictly speaking, describe, about the sun, elliptical orbits, nor areas proportional to the times: but Newton shews[a] that in a system of bodies moving about one considerably greater than all the rest, and such is the case with the system to which we belong, the proportional areas and the elliptical orbits are, by those planets which have no satellites, described, very nearly, about the common centre of gravity, and, with respect to each of those planets which have satellites, the Earth, Jupiter, and Saturn, he observes[b] that it is the common centre of gravity of the primary and all its satellites which describes, nearly, the elliptical orbit and areas proportional to the times. He adds that the sun, himself, is made to describe an orbit about the common centre of gravity of the system, that the earth and moon revolve about their own common centre, in a month; and, in like manner, each primary planet and its secondaries revolve about the centre of its particular system.

Newton admits that the force of the attraction exercised by the planets on one another should be taken into consideration, in a theory of their motions: he observes that, at the conjunctions of Jupiter, Saturn and the sun, the attractions exercised by the first and last on Saturn are, to one another, in the ratio of 1 to 211, nearly, and he shews that there arises a sensible perturbation in the orbit of Saturn by the action of Jupiter; from which, according as the former happens to be situated, with respect to the line of its apsides, at the time of the conjunction, the eccentricity may be augmented or diminished; its aphelion, also, will be made to advance or to retrograde, and its mean motion accelerated or retarded: the whole error in the mean motion of Saturn he supposes to be equal to about two minutes annually[c], but he considers this quantity to be superior to the

[a] Princip. Lib. I. Prop. 68, cor. [b] Ibid. Lib. III. Prop. 13
[c] Ibid. Lib III Prop. 13.

error produced by a similar cause in the mean motions of any of the other planets.

In all his investigations, Newton supposed the apsides and nodes of a planet's orbit to be immoveable and, in fact, in his time, the observations were not sufficiently precise to put the question concerning the quiescence or motion of the apsides quite beyond a doubt; yet he shews how, by a law of attraction differing from that of the square of the distances, inversely, a movement of those points must necessarily take place: he proves also, that the movements would be retrograde if the attraction were inversely proportional to a power of the distance less than the square, and direct, if inversely proportional to a power greater than the square, and, as an example, he calculates that, if the centripetal force were inversely as the power $2\frac{49}{243}$ of the distance, the revolving body would go through an angle of 363 degrees during the time of a revolution from one extremity of the major axis to the same, and, consequently, that this extremity would advance three degrees during the revolution. His inference is, that such would be the result if an external or perturbating force should act upon a planet to alter its gravitation to the sun, from the general, to that particular law.

To explain the theory of perturbation in a system of three bodies, consisting of the sun and two planets of which every one attracts the others. Let S [Plate V. fig. 4] be the sun; M the disturbed planet, moving, originally, in the elliptical orbit P M A, and P′ the disturbing planet, whose orbit is here supposed to be on the exterior of the other; join P′ and M, and draw the line P′ P through S Take M C to represent the sum of the attractions of M and P′, at the distance P′ M, on each other, and resolve it into the forces M B and M D, of which the former is equal to the sum, and parallel to the directions of the attractions of P′ and S on each other, then the force M B, expressing that part of the disturbing force of P′ which acts equally, and in parallel directions on M and S, produces no change in the relative positions of those two bodies; M D is, therefore, the only force we have to consider, let this force be resolved into the two forces M E and M F, of which the former acts in the direction of the radius

* Princip. Lib. I. Prop 45.

vector M S, and the other, in that of a tangent to the orbit of M. Now, while the force M E tends towards S, it is evident that the attraction from M towards S is increased in consequence of the disturbing force, but the force M E is nearly in direct proportion to the distance M S[a], while the attraction of S is inversely proportional to the square of the same distance: hence the whole attraction of S on M is inversely proportional to a power of S M which is less than the square and, as was said above, the line of the apsides of the orbit will be caused to retrograde about S. It is evident that this effect will be the greatest when the planet M is nearly in quadrature with respect to S and P; that is, at Q or Q′, where the tangential force M F coinciding with B M, no perturbation in that direction takes place. On the other hand, when M E is in an opposite direction to M S, the attractive force of S upon M is diminished in consequence of the disturbing force, by a quantity which is nearly in direct proportion to M S; or, in other words, the attraction from M towards S is, as far as this distributing force is concerned, nearly in inverse proportion to the distance M S, while, by the general law of gravitation, it is inversely proportional to the square of that distance; consequently the whole attraction of S on M will, in the present case, be inversely proportional to a power of S M which is greater than the square; and it will follow that the line of the apsides will move in direct order about S, the effect will be the greatest when the planet M is in conjunction with, or in opposition to P′, at which times the tangential force M F vanishes.

It is a consequence of this variation in the attraction of S upon M that the orbit of this planet is rendered more or less eccentric according to the position of the line A P, of the apsides, with respect to the line P′ S; when the former is in coincidence, or nearly so, with the latter or, as it is said, when the line of apsides is in, or about the syzygy, the eccentricity is increased, and a contrary effect takes place when the line of apsides is in, or nearly in quadrature, that is, at right angles to P′ S. It is explained by Newton[b] that, in the first case, the planet M, in passing from the aphelion, towards the perihelion point, being disturbed by a perpetual accession of new forces tending to S,

[a] Princip. Lib. I. Prop 66, cor 7. [b] Ibid. cor 9.

will approach constantly nearer to the latter body than if it described the simple undisturbed elliptical orbit, till it arrives at the perihelion; after which, in returning towards the higher apsis, the diminution of the disturbing force being in a higher ratio than its previous augmentation, the planet, till it arrives at the aphelion, is carried continually further from S, than if it had moved in an elliptical orbit, and thus, the sun still occupying one of the foci, the orbit is rendered more eccentric, the effect is evidently the greatest when the apsides are exactly in syzygy In the second case, the accession of new forces acting on M will, for the same reason as before, elongate the orbit in the direction of the line P P′, and, consequently, will diminish the major axis and the eccentricity, the effect being the greatest when the apsides are exactly in quadrature.

In the tenth corollary to the proposition last quoted Newton shews that if the plane of the orbit of M be inclined to some other plane, as that of the ecliptic, which intersects it in a line passing through S, the force which represents the attraction of P′ upon M being decomposed into two forces, of which one is in the plane of the ecliptic and the other perpendicular to it, the latter force, except when the lines of nodes is coincident with P′ P, will, by acting on M, have the effect of drawing the orbit of this planet towards the plane of the ecliptic, so that the inclination of the two planes and, consequently, the latitude of the planet will undergo variations independent of those which would be experienced in an undisturbed elliptical orbit, and the effect of this attraction will, of course, be the greatest when the nodes are in quadrature. When the planet M is in either node and, also, when at 90 degrees from thence, it is evident that the attraction of P′ will have no effect in changing the places of the nodes; but, in every other position of the planet, the decomposed part of the attraction of P′, which is perpendicular to the ecliptic, together with the force which causes the planet's motion in the orbit, produce a force, oblique to the plane of the ecliptic, by which the direction of the planet's path is changed, and made to intersect the ecliptic in various places and at various inclinations according to the intensities of the acting forces; so that both the original inclination is perpetually changing and the

nodes are made to move unequably on the ecliptic, in retrograde order; and Newton observes[a] that, since the nodes are either stationary or moving, thus, *in antecedentia*, upon the whole, in each revolution about the sun, they are made to retrograde, with respect to the places of the fixed stars He adds[b], that if P′ be very remote, when its place is compared with those of the other two bodies, the mean motion of the aphelion will be nearly in a constant ratio to the mean motion of the nodes, both being directly proportional to the periodical time of the revolution of M about S, and inversely proportional to the square of the periodical time of the revolution of P′ about S.

The perturbating force exercised by an inferior, on a superior planet produces effects similar in kind but, generally, contrary in direction, to that exercised by a superior on an inferior planet; and the circumstances above exhibited will apply to the disturbing force exercised by the sun on the moon, if we suppose the former to be represented by P′; the latter, by M, and if S represent the earth

If the moon's orbit were undisturbed, the equation of the centre, which depends on the angle at the moon, subtended by the eccentricity of the orbit, or by the distance of its centre from one of the foci, would be always the same when the anomaly, or distance of the moon from either apsis, is the same. But, as we have seen that the perturbating force in M S, the radius vector, increases the eccentricity of the orbit when the moon and the line of the apsides is in or near the syzygies, and diminishes it when the moon and the line of the apsides is in or near the quadratures, and, as the moon's gravity to the earth is always augmented when she is in quadrature and diminished when in syzygy by the action of the same disturbing force, it follows that, when the apsides are in syzygy and the moon in quadrature, the augmentation of the eccentricity is the greatest; and, when the apsides are in quadrature and the moon in syzygy, the diminution of the eccentricity is, also, the greatest: again, the equation of the centre augmenting and diminishing with the eccentricity, its maximum and minimum state will coincide, respectively, with the two last mentioned situations of the moon

[a] Princip Lib. I. Prop 66. cor. 11. [b] Ibid. cor 16.

and the line of her apsides; and its mean state, with the two former. Now the ancients, previously to the time of Ptolemy, determined the equation of the centre by means of the eclipses of the sun and moon, that is, for times when the moon was in the syzygies; and, according to Hipparchus, when the apsides, also, were so situated, the equation was equal to 6° 20′, but, when in quadrature, to five degrees only. Ptolemy, on the other hand, observing the moon when in quadrature, found that if the apsides, also, were in quadrature, the equation was 6° 20′, and, if in syzygy, it amounted to 7° 40′. The difference, therefore, between the mean state and either of the extremes, which is equal to 1° 20′, he denominated the second lunar inequality; and this is the equation which was, subsequently, designated the evection, and whose physical cause has been above explained. The evection vanishes when the moon is in syzygy, and then, the equation of the centre coincides with that determined by Hipparchus; but, whether the apsides be in syzygy or quadrature, if the moon be in the latter position, the evection is a maximum for, then, the equation of the centre differs by about 1° 20′ from the values assigned to it by that ancient astronomer.

It is remarkable that Newton does not enter into any computation concerning the effects of the perturbation last mentioned; he merely shews [a] the proportion which the disturbing force of the sun, in the direction of the radius vector, bears to gravity; and he, probably, considered that the particular values might be easily deduced from what he had said in the sixty-sixth proposition of his First Book. But that inequality of the moon's motion which is called her variation, and which was discovered by Tycho Brahe, is shewn, in the twenty-sixth and twenty-ninth propositions of the third book, to depend upon that decomposed part of the sun's attraction of the moon which acts in the direction of a tangent to her path about the earth, as above explained, this force alternately accelerates and retards the movement of the moon in the different quadrants of her orbit, and is reduced to nothing in the conjunctions and oppositions because, then, the whole attraction of the sun acts in the radius vector; it is,

[a] Princip. Lib. III. Prop. 25

also, nothing in the quadratures, since, there, the tangential force is equal to the attraction exercised on the earth, by the sun; in consequence of which no change, on this account, takes place in the moon's motion relatively to that of the earth; but its effects are the greatest when the moon is in the octants, or at 45 degrees from the points of syzygy and quadrature, in which situations it amounts to 35′ 42″ nearly. Newton makes it equal to 35′ 10″, but he supposes the earth to be in the centre of the moon's elliptical orbit, and he has neglected the difference arising from the ellipticity of the orbit of the earth.

A fourth inequality of the moon's motion, which was discovered by Kepler, and is called her annual equation, is shewn by Newton, in the scholium to the thirty-fifth proposition of the third book, to arise from the variations in the dimensions of the moon's orbit, caused by the different degrees of attraction exercised by the sun on the earth in different seasons when, from the ellipticity of the orbit, the earth is at different distances from him. Thus, at the time the earth is in perihelio, and the moon in syzygy, the increased attraction of the sun causes a corresponding increase in the length of the major axis of the moon's orbit; and, in the aphelion, a contrary effect takes place by the diminished attraction, but the moon moves slower when her orbit is expanded, and faster when contracted; and, for the moon's movement in longitude, he makes the amount of the equation, when a maximum, equal to 11′ 50″: at present, astronomers make it something less.

These four inequalities of the moon's motion are all that were discovered by observation, but the theory of gravitation has made us acquainted with twenty-eight others, which probably never would have been, without it, distinguished from each other; of these Newton mentions one which he denominates the semi-annual equation, and which he shews to arise from the different positions assumed by the line of the moon's nodes; when this line passes through the sun, the whole attraction of the latter is, evidently, exerted in the plane of the ecliptic; but, in proportion as it deviates from that position, the attraction is diminished by the obliquity of its line of action to that plane; and, thus, variations take place in the moon's movement: the inequality

is a maximum when the nodes are in the octants with respect to the sun, and then, according to Newton, it amounts to 47 seconds; it is now made equal to about 60 seconds, and vanishes twice in a year, at the times when the nodes are in conjunction with the sun.

The cause of the retrograde movement of the nodes of any planet's orbit is explained, as we have said, in the first book of the Principia; and Newton computes [a], from the theory there exhibited, that the mean annual motion of the moon's nodes, produced by the sun's attraction, is equal to about 19° 18′. He does not enter into any investigation concerning the amount of the progression of the moon's apogeum, but he asserts [b], and probably, by observations made in his time it had been found, that it was equal to about three degrees in each revolution of the moon. The cause of the progression of the apsides of any orbit is shewn in the proposition last quoted; and it is observed [c] that the variations in the degree of solar attraction will produce corresponding variations in the movements both of the apsides and nodes.

The particles of matter composing the earth being endowed with attractive qualities it is evident that, if the earth had no movement of rotation, those particles would arrange themselves uniformly about the centre of the mass, which would, then, assume the figure of a perfect sphere; but, in consequence of that rotation on its axis, the particles acquire a centrifugal force which is so much the greater in each, as the particle is more distant from the axis of revolution; hence, the matter about the equatorial regions was compelled to recede from the centre till an equilibrium took place between the attractive and centrifugal forces, and the matter about the poles subsiding towards the centre to supply the deficiency there, it followed that the equatorial, exceeded the polar diameter in length, and the earth assumed the form of an oblate spheroid [d].

In investigating the figure of the earth, Newton supposes that the latter was originally a fluid mass revolving on its axis; that its particles mutually attract each other, and that every part of

[a] Princip. Lib III Prop. 31, 32.
[b] Ibid Lib. I. Prop 45, cor. 2.
[c] Ibid. Lib. III. Prop. 35. schol.
[d] Ibid. Lib. III. Prop. 18.

the surface is in equilibrio between the gravitating and centrifugal forces, and he concludes[a] that the ratio of the polar, to the equatorial diameter is as 229 to 230. he shews, also, that the forces of gravity at the poles and at the equator are inversely proportional to the lengths of those diameters, and that, in proceeding towards the equatorial regions, the diminution of intensity is proportional to the square of the sine of the latitude The hypothesis of Newton was, immediately afterward, modified by Huygens, who, assuming that the earth is a spheroid composed of infinitely thin strata diminishing in density from the centre to the surface, and infinitely great at the centre itself, and, also, considering that each particle tends towards the centre of gravity of the terrestrial mass, with a force inversely proportional to the square of its distance from that point, obtained a value of the compression which La Place considers as exceeding the true value, while that found from the preceding hypothesis falls short of it Now it is shewn by Newton[b] that the attractive influence of a body, exerted obliquely upon the annular protuberance of another body, whose form is spheroidal and which is endowed both with a rotation on its axis and a revolution about the attracting body, will produce a variation in the obliquity of the axes of the two movements and a retrograde movement of the nodes of the protuberance: but the earth's protuberant equator is inclined to the ecliptic, which is the plane of the earth's revolution about the sun, in an angle of about 23½ degrees; and, therefore, a decomposed part of the solar attraction, acting upon the equatorial regions of the earth perpendicularly to the ecliptic, combined with the force with which a point on the circumference of the equator revolves about the axis of the latter, will, necessarily, produce a continual diminution of the obliquity of the ecliptic and a retrogradation of the equinoctial points; just as the attraction of the sun on the moon, combined with her revolution in her orbit, causes a variation in the obliquity of that orbit and a retrogradation of its nodes· supposing the excess of the terrestrial spheroid above the inscribed sphere to surround the equator of the sphere like a ring, Newton finds that the amount of the retro-

[a] Princip. Lib. III. Prop. 19.

[b] Ibid. Lib. I. Prop. 66. cor. 20.

gradation of the equinoctial points would be, to that of the moon's nodes, in the same proportion that the sidereal day bears to the period of a sidereal revolution of the moon [a]. He shews, however, that this result requires modification because the ring, by adhering to the terrestrial sphere, communicates to the latter its own retrograde movement, which renders the actual retrogradation of the equinoctial points less than that of the nodes of the ring, in the proportion of the mass of the ring to that of the earth.

The action of the moon upon the equatorial regions of the earth produces, also, changes in the obliquity, and a retrogradation of the equinoctial points; but the intensity of her attraction is more variable than that of the sun, because the influence of the former body can only be directed, in the same manner, to the same points of the equator, at the end of every revolution of her nodes. In the proposition above quoted Newton has expressed his determination, from theory, of the mean annular amount of the retrogradation; of which the part due to the solar attraction is stated to be about 9 seconds, and that due to the general attraction of the moon, 41 seconds, nearly; hence the whole is made equal to about 50 seconds. From the movement, thus explained, of the equinoctial points, arises the observed general precession of the stars, whose longitudes are reckoned from one of those points, and its amount is nearly the same as that which is assigned by Newton. The variations of these attractions Newton does not consider, but, in the twenty-first proposition, speaking of the solar nutation of the earth's axis, he observes that it must be very small and scarcely perceptible.

The attractions of the sun and moon are proved, also, to be the causes of the tides raised in the ocean, and Newton's explanation of these phenomena is contained in the corollaries to the sixty-sixth proposition of his first book. In the second, he shews that any body revolving originally in a circular and uniform manner about the earth, and disturbed by the attraction of the sun, will have its velocity continually accelerated in its approach towards the points of conjunction and opposition with the sun, and continually retarded in its approach towards the

[a] Princip. Lib. III Prop. 39

points of quadrature; and the same thing is shewn [a], of a ring of fluid particles surrounding the earth in the plane of the equator, such a fluid ring, therefore, representing an ocean so situated, it is evident that the velocity of the fluid particles in syzygy, being greater than that of the solid matter of the earth, an elevation of the fluid will there take place which, consequently, by the revolution of the earth on its axis, will cause two high tides to be raised, at any one place, in the time of a diurnal revolution, by the diminished velocity of the fluid in quadrature, there will, also, be two low tides in the same time. Like effects are supposed to be produced by the attraction of the moon on the waters, and, in the twenty-fourth proposition of the third book, it is shewn that the tides will be higher than ordinary when the luminaries are in conjunction and opposition, and lower, when one is in quadrature and the other in syzygy. thus are the spring and neap tides, which occur alternately twice in each month, accounted for. Newton shews, also, that the highest waters are continually taking place at two opposite points of the earth's surface which have the moon near their zenith or nadir; hence, when the luminary has considerable declination from the equator, it follows, on account of the obliquity of the earth's axis of rotation to the line of the apsides of the spheroid formed by the lunar attraction, that the tide raised when the luminary is on the meridian of a place, or rather when it has recently passed it, is considerably higher, or lower, than that which occurs after twelve hours, at the same place. He calculates moreover [b] that, in the open seas, the sun's attraction is sufficient to raise the tides nearly two feet above the mean level, and that of the moon, about 9 feet, so that, when the luminaries act together, their united powers will raise them 11 feet; but this is independent of the local and other causes which may accelerate or retard the flowing of the waters.

The attraction exercised by the earth on the moon, combined with the rotation of the latter on her axis, is shewn to have caused a small elongation of the diameter which, when produced, passes through the earth, with a corresponding contraction of that diameter of the moon's equator which is at right

[a] Princip. Lib. I. Prop. 66. cor. 18, 19. [b] Ibid. Lib. III. Prop 36, 37.

angles to the former; and to this is ascribed the constant presentation of nearly the same face of the moon to the earth, for, though foreign perturbations may cause the former of these diameters to deviate from the line joining the centres of the moon and earth, the attraction of the latter will presently bring it back, thus, it will be made to oscillate about its mean position within certain limits of very small extent: and this tendency of the same face of the moon towards the earth causes her, with respect to any fixed point in space, to make one revolution on her axis during the period of one revolution in her orbit, about the earth: and subsequently to Newton's time, it has been proved that, from the same cause, the nodes of her equator and those of her orbit retrograde with equal velocities

The latter part of Newton's third book contains his theory of comets. he there shews that they describe about the sun elliptical curves which, however, do not differ much from parabolas, to a certain extent on each side of the perihelion point; hence he considers that they return, periodically, to the part we occupy in the system, and he gives a rule for determining, by computation, the forms of their orbits and the laws of their movements in them: for this purpose he proposes [a] to have three observed geocentric places of the comet, with the positions of the earth at the times of observation; and to find, by trial, a parabola, having the sun in its focus, and intersecting the three visual rays in the directions of which the comet is seen, in points corresponding with the heliocentric places which a body should have, at the given times, when moving in an orbit of that figure. In those cometary orbits which have been determined by computation, it has been found that the squares of the times of revolution are proportional to the cubes of the mean distances, and, where the periodical returns of comets have not been observed, the velocities of those bodies in the perihelion points of their orbits have been found to be, also, in the subtriplicate ratio of their perihelion distances, which Newton has demonstrated to be a law of motion in a parabolic curve, hence it follows that the comets, as well as the planets, are subject to, and describe their orbits in virtue of the sun's attractive power. The

[a] Princip Lib III Prop 41.

inequalities of the motions of comets are, however, far more considerable than those of planets; for the inequalities are proportional to the eccentricities, and the eccentricities of comets are very great.

On the publication of Newton's work, though to men of ordinary attainments in science, it was a sealed book, and though it appears that only a few of the first mathematicians in Europe could, at that time, be said to have understood it, the jealousy of this great man's contemporaries was the cause that many efforts were made to detract from his merit; it was particularly urged that the principle of gravitation was not his discovery, and that it had been clearly announced long before his time; as if the claims of this illustrious philosopher to the gratitude of posterity was founded only on the knowledge of a power in nature, and not on the discovery of the means through which that power produces the phenomena of the earth and celestial bodies; a discovery which could only have been made by the exertion of a transcendent intellect, and which has rendered Newton as much superior to any preceding philosopher as the man who dispenses his wealth for the benefit of his species is to one who suffers it to remain unproductive in his coffers. It is true that Kepler supposed the existence of an attractive force in the sun and planets, and that he considers it as changing with the variations of distance, but he was far from having any fixed ideas concerning the law of the variations, and he speaks as if he thought the movements of the planets were the result of intelligences or souls inherent in those celestial bodies: it may, also, be alleged, and with greater reason, that Galileo and Bullialdus were aware of the true law by which the attractive force diminishes, but, in their hands, the principle remained fruitless since they do not introduce it into any part of the planetary theory The same thing must be said of the principles enunciated by Dr. Hook, which only shew that the materials for the work had been prepared by different hands; the architect was still wanting, and Newton was happy in arriving at the critical moment to design and raise the edifice.

The law of attraction which Newton had assumed was not, moreover, immediately received by all his contemporaries, and

those learned men who could not avoid admiring the profundity of his genius in deducing the most important phenomena of the heavens from a single principle, nor acknowledging that a central attractive force actually resided in the sun, yet felt disposed to object to the principle itself, so far at least as concerned the mutual attractions of material bodies, on the ground that it seemed to be a return to the doctrine of occult qualities which had been, long before, so justly proscribed, and that it was incapable of explanation by any known laws of mechanical action, such objections, however, fall to the ground when it is considered that there is the same evidence for the attraction of gravitation as for those of magnetism and electricity, whose existence cannot be doubted though they are not apprehended by the senses, and though no conception can be formed of their mode of action. It is, therefore, consistently with sound philosophy that Newton, while deducing the figure and movements of the earth and planets from the action of gravity, treats the principle as a law of nature with whose origin he has no concern, but which, being adopted as an hypothesis, is found to satisfy all the known phenomena of the celestial movements.

Descartes, as we have seen, had attempted to account for the motions of the planets by supposing them to be carried round the sun in vortices, and, in an age when the hypothesis was generally received among the learned, it is not surprising that Newton should have thought it necessary to take the trouble of refuting it: this he has done in the second book of the *Principia* [a], by showing, first, that the molecules of a fluid vortex would revolve with such velocities about a central body like the sun, whose rotation was the cause of their motion, that the periodical times of their revolutions would be proportional to the squares of their distances from it; whereas the planetary bodies, which, as he shews, ought, by being carried round in the vortex, to revolve with velocities expressed by that law, have, in fact, their periodical times of revolution in the sesquiplicate ratio of their distances, and, in the next place, that since the interior molecules of the fluid revolve with the greatest velocities, they would press against those towards the exterior;

[a] Corollaries to Prop 52.

and the whole being finally dissipated in infinite space, the vortex and the movement of the bodies placed in it would, at length, cease To these arguments he adds, that the motions of comets, taking place freely in all directions, entirely destroy the hypothesis. But the desire to refer the laws of Nature to mechanical causes as far as possible was, in those days, strongly felt, and Sir Isaac Newton himself, probably in compliance with the taste of the times, and when not restrained within the limits prescribed by geometry, attempts, but in the modest form of a query, to explain the cause of gravitation by the existence of a fluid surrounding the sun, and increasing in density as it recedes from that luminary, so that a body placed in the fluid would be impelled towards the sun by the excess of the pressure on the exterior, over that on the interior side[a]. It appears also, that Bernouilli, dissatisfied with the hypotheses both of Descartes and Newton, proposed another, in which he imagined a torrent of fluid matter to be continually setting in, from the exterior of the vortex towards the centre, and, thereby causing a tendency of all the planets towards the sun. With respect to that of Newton, it is proved by Mr. Vince, in his observations on the hypotheses assumed to account for the cause of gravitation[b], that it is not possible for any law of the variations in the density of the fluid, in terms of the distance of its molecules from the sun, combined with any law of the variations in the repulsive force of the molecules of the fluid, to satisfy the laws of gravitation: and the same astronomer justly observes, that all such hypotheses have difficulties as great as those which they are intended to solve; since the nature of the repelling power, by which is constituted the elasticity of the fluid, is as remote from our apprehension, and as much requires explanation, as that of gravity itself.

From the wild fancies above hinted at, it is with pleasure we turn to notice some remarks of Newton, in his letters to Dr. Bentley, in answer to the enquiries made by this distinguished scholar concerning that part of the philosophy of Epicurus in which it is assumed, that the earth and celestial bodies formed themselves by the condensations of a matter previously diffused,

[a] Optics, Quæst. 21. [b] Art. 11.

uniformly, through the universe. Newton first shews the absurdity of supposing that the particles of matter, having a tendency to unite by a principle similar to that of gravity, could, at any time, be uniformly diffused in space, since, from the first moment of their existence, the condensation must have commenced he then observes that, if matter were evenly diffused through a finite space, and its particles were endowed with gravity, those particles would fall to the middle of the space, and there form one spherical mass; or, if diffused through infinite space, it would form an infinite number of great masses which, if the matter were lucid, might constitute suns and stars, and he adds, it is inexplicable by natural causes that the matter should so separate itself as to form two different kinds of bodies, one lucid like the sun, and the other opaque like the planets. Lastly, he states that the motions which the planets have could only be caused by an intelligent agent: gravity alone, he observes, might put the planets in motion in rectilinear directions, but, to produce a circular motion about the sun, an independent and transverse force is necessary, to which the quantity of matter in the revolving body must be duly adjusted.

It is much to be regretted that Newton omitted to exhibit the results of his researches in formulæ, and that he chose to demonstrate his propositions in the manner of the ancient geometricians rather than use the analytic method to which he had, then, recently made so important an addition by the discovery of the infinitesimal calculus. This has thrown a certain degree of obscurity over his reasonings and as, in a few instances, where the common geometry failed, he has permitted himself to depart from that practice, there has arisen a want of unity in his investigations, which detracts materially from the merit of his work, in every other respect so truly admirable. It is possible that, since the powers of the fluxionary or differential methods were, then, far from being completely unfolded, and since cavils were, then, often raised against its logical propriety, Newton might, on those accounts, have been induced to prefer the ancient processes in his researches, and avoid, as much as possible, the introduction of an analysis which had not the advantage of being sanctioned by general approbation, and which

was not, even, generally understood Since the time of our great philosopher, this analysis, the discovery of which forms one of his titles to immortal fame, and which has received so many important accessions from the labours of the mathematicians of the continent, has been extensively applied to the subjects he had partially investigated; and, by its powerful aid, general solutions have been obtained, which, being found in every case to accord with the results of observation, establish the justness of the hypothesis from which they were derived, and determine the Newtonian theory to be the immoveable basis of physical astronomy.

CHAPTER XXI.

IMPROVEMENTS IN PRACTICAL ASTRONOMY.

Imperfection of the ancient astronomical instruments.—Methods of finding the direction of the meridian, and the latitude of an observatory.—Employment of pendulum clocks in astronomical observations.—Application of the micrometer to telescopes.—Transit instruments used in observatories.—Manner of determining the times of the equinoxes and solstices and the places of stars.—Discovery of the transmission of light, in time, through space.—Attempts to find the parallaxes of fixed stars.—Discovery of the aberration of the stars.—Discovery of the lunar nutation.—The law of astronomical refraction determined.—The parallaxes of the moon and Mars found by observation.—The use of the observed transits of Venus in finding the sun's parallax.—Invention of the achromatic telescope.—Improvements in the instruments used for nautical observations.—The lunar tables improved by Mayer.—The employment of chronometers for finding terrestrial longitudes.

THE present advanced state of astronomical science being due as much to the improvements made in the instruments employed for observation as to those in the analysis by which the celestial movements are investigated, it will be proper, here, briefly to recapitulate what has been said concerning the ancient instruments, and shew the nature of those by which they have been superseded.

The oldest observations were made, as we have stated, with the gnomon; by this instrument the days of the equinoxes and solstices were observed, and, the direction of the meridian being traced, the time of the sun's arrival in the plane of that circle, his meridional altitude and declination were, also, ascertained; its simplicity, and the opinion that, by making it of great height, proportional accuracy in the observations would be acquired, have been the causes that its use was prolonged almost to our own times: the last instrument of the kind is that which was formed, in 1575, by Ignatius Dante in the church of St. Petronius, at Bologna, and consisted of a meridional line traced on the pavement, with an aperture in the wall through which the

rays of the sun were transmitted; we have related that, in 1653, Cassini restored this line, which, becoming again deranged by the sinking of the pavement, was finally retraced by Zanotti in the year 1776.

But the gnomon was never capable of being employed to obtain the differences of longitude, or of right ascension or, in fact, to obtain any angular distances between celestial bodies, when they were not on the meridian we have mentioned the equatorial armillæ, the quadrants and parallactic instruments which, instead of it, were used for those purposes by the ancients, and it is worthy of remark that, if we omit those which were adjusted to coincide with the plane of the ecliptic, which have been long since laid aside, the others are still retained, but in improved forms, in the modern observatories· our mural quadrants and circles, and zenith sectors still serve, like the meridional armillæ of the ancients, to find the polar distances of celestial bodies; and our equatorial instruments are used to obtain the right ascensions and declinations of such as cannot be observed on the meridian.

The operations of practical astronomy require that the direction of the terrestrial meridian should be accurately determined, its trace on the ground was, no doubt, at first, obtained by marking the extremities of the shadow cast by a gnomon, when they fell on the circumference of a circle described about the foot of the gnomon as a centre, but it is probable, also, that very anciently the practice had been adopted, of observing the times when the sun had equal altitudes before and after noon; these being found, and half the interval, corrected on account of the change produced in the sun's horary angle by the change in his declination, being added to the time of the first observation; there was obtained the time of the sun's arrival on the meridian. The middle of the azimuthal angle between the two places of the sun, similarly corrected, fixed the position of the meridian itself: but we now correct the position thus obtained by methods which will be presently mentioned. The planes of our mural instruments are made to coincide with that of the meridian; and the zenith distances of celestial bodies being observed when they arrive in this plane, their declinations are immediately found, the

latitude of the place being supposed to be known. The meridional altitudes of the sun on the days of the solstices were long employed for finding this last element, but Tycho Brahe seems to have been the first astronomer who determined it by the altitudes of a circumpolar star, taken at times when it was on the meridian above and below the pole.

But the circumstance which principally distinguishes the modern, from the ancient practice of astronomy is the frequent use made of instruments for measuring time; these, by the application of the pendulum, having been, in a recent age, rendered capable of marking its subdivisions with very great accuracy. The first notice we have concerning the employment of a pendulum to ascertain small portions of time is in an account of the method by which Mouton, of Lyons, attempted to measure the diameter of the sun; this consisted in counting the number of vibrations performed while the disc of the luminary was passing over a vertical line situated in the plane of the meridian; the arc of the equator described by the sun, in the time of a given number of vibrations, being determined by computing the angle at the pole corresponding to that between the vertical planes passing through two plumb lines situated near the meridian, at some distance from the eye, and counting the number of vibrations performed while either limb of the sun, on the day of the equinox, was moving from one line to the other. Vindelinus, Kircher and Ricciolus had also made use of pendulums for ascertaining the duration of phenomena; but Huygens was the first to determine what should be their length, that each vibration might be performed in one second of time: in order to mark the number of vibrations made in a given time, he conceived the idea of applying palettes to the upper extremity of the pendulum and causing them to catch in the teeth of a wheel which was connected with the machinery of a clock, the movement of whose index would shew the time, as well as the number of vibrations. We have said that, in the hope of rendering the vibrations isochronous, in great and small arcs, he endeavoured to procure a cycloidal movement in the pendulum, agreeably to the idea of Galileo, but this having been, since, found practically impossible, the effort was abandoned, and the

error arising from the want of that isochronism is rendered insensible by causing the vibrations to be of small extent, on each side of the vertical line passing through the point of suspension The expansion and contraction of pendulum rods by changes in the temperature of the air were, at first, the causes of much irregularity in the times of vibration; but these errors are, now, very nearly corrected by forming the rod with metals possessing different degrees of expansibility by heat, and applied in such a way that the variations of length take place in contrary directions.

The invention of telescopes was almost immediately followed by their application to the mural quadrants employed in observatories, where they superseded the plain sights with which those instruments had been before furnished. and an important improvement in the practice of observing was, shortly afterwards, made, by adapting to the eye-pieces of telescopes an instrument for measuring very small angles The invention of the micrometer, as the instrument was called, is usually ascribed to Huygens, but the priority of claim to this honour is disputed between Gascoigne, in England, and Huygens, Auzout, Picard and Roberval, in France; and, probably, all these astronomers contributed to bring it to a convenient form, it appears that the French mathematicians did not use it before the year 1667, and there is evidence that it had been employed in England in 1640. In the original construction, and the instruments are still often made on the same principle, there were placed across the eye-piece of the telescope a fixed wire, and another which was made to move parallel to it by means of a screw; and thus the two wires could be made to embrace the visible disc of the sun, moon or a planet, or the distance between the moon and a star, at the time of an appulse, the values of the angular diameters, or the small distances of the celestial bodies, being given by a scale whose index moved with the wires.

In the year 1644, Roemer, a Danish astronomer, introduced the method which has ever since prevailed, of observing the right ascensions of celestial bodies, directly, by means of what is called a transit instrument, that is, a telescope attached to a horizontal axis, perpendicular to its length, and moveable

only in the plane of the meridian, by which the times of the transits, or passages of those bodies over the meridian, can be observed. The instrument is accompanied by a pendulum clock, whose index is set to the commencement of the hours on the dial-plate at the moment when the vernal equinox is on the meridian of the place; and the observation of the time at which the centre of any celestial body coincides with the meridional wire, in the axis of the telescope, shews the angular distance of the horary circle passing through the body, from the equinoctial colure, by the time elapsed since the vernal equinox was on the meridian, and, as one hour of sidereal time corresponds to 15 degrees on the equator, it is evident that, allowance being made for the error of the clock, the right ascension of the celestial body is immediately known. The direction of the meridian may have been determined in the manner above mentioned, but the use of the transit telescope requires that it should be ascertained with extreme accuracy, and several methods are employed for finding the error, in the position of the telescope, with respect to the meridian; one of these consists in observing, with the telescope itself, the transits of a circumpolar star both above and below the pole, and, as the interval between the two transits will be exactly twelve hours of sidereal time, when the star is, in both situations, on the plane of the meridian; the excess or defect, if any should be observed, will afford the means of computing the deviation of the instrument from that plane; a second method, but which is more dependent on a previous knowledge of the star's place, consists in comparing the difference between the times of the observed transits of two stars, which pass the meridian, respectively, near the zenith and near the horizon, with the computed difference of the true right ascensions of the same stars; for these differences will be identical when the telescope moves in the plane of the true meridian.

The time of the arrival of the vernal equinox on the meridian is known when the absolute right ascension of any one star is given, for, by setting the index of the sidereal clock, when the star is on the meridian, to the hour which expresses that right ascension, the arrival of the index at the commencement of the

hours will be simultaneous with that of the equinoctial point, in the plane of the meridian: it is necessary, therefore, to ascertain the time at which the sun will be in the equinox, and the difference between the right ascensions of the sun and star at that moment. Now, by means of telescopes, the principal fixed stars and some of the planets can be seen in the day time, even when they arrive on the meridian nearly at the same time as the sun, astronomers are, therefore, at once, enabled to obtain the positions of many stars with respect to the sun by direct observation, and, from these, the positions of all the other stars may, consequently, be determined: thus the intervention of the moon or Venus, which was formerly requisite in fixing the longitude or right ascension of any star, and which was, at best, an uncertain process, is entirely superseded, it only remains, therefore, to shew in what manner the distance of the sun from the equinoctial point is now ascertained.

For this purpose, and Flamstead was the first to put the method in practice, the meridional altitudes of the sun are, daily, taken, for a few days before and after that of the equinox, from whence are determined his corresponding distances from the equator, and his daily or hourly motion in declination. On the same days, the differences in right ascension, of the sun and of a star which arrives on the meridian nearly at the same time, are also to be observed by the transit instrument, and the daily or hourly motion of the sun in right ascension, thence, computed; the place of the star being supposed to be fixed in the heavens, or the changes to which it is subject being estimated from the existing tables. Then, as, during short portions of time, the sun's movements in right ascension and declination may be considered uniform, we shall have, by proportion, the distance of the sun from the equinoctial point at the time corresponding to that of any of the observed declinations, or, if the obliquity of the ecliptic be taken from the existing tables we can, from the daily declinations, compute by spherical trigonometry, the like distances of the sun from the equinox: the daily movements of the sun in right ascension will give the time of his arrival at the equinox, and the daily difference of the sun's and star's right ascensions determine, for each day, the distance of

the star from that point; and a mean, both of the times and distances, for all the observations, will give the moment of the sun's arrival in the plane of the equator, and the place of the equinox, by its distance from the star, with great correctness. In a similar manner, the moment of the sun's arrival at either solstice, and the obliquity of the ecliptic to the equator, can be computed.

The right ascension and declination of a celestial body are the two essential elements for fixing the position of the body in the heavens; and from them, the longitudes and latitudes may be deduced by computation, after correction for the various causes of error to which all observations are subject· the method of observing by the transit telescope and mural instrument is, undoubtedly, that which is most easily practised and is, at the same time, the most accurate, since the verifications of the instruments can be made with the greatest certainty, on these accounts it is now universally adopted in fixed observatories.

A knowledge of the causes of the errors affecting the apparent places of celestial bodies was unfolded in proportion as instruments were rendered capable of giving those places with precision and repeated observations afforded the means of investigating formulæ by which the errors might be computed and reduced to tables, for the convenience of readily taking out the corrections necessary to obtain the true places, from those which were given, directly, by the instruments. It had been suspected by Galileo that light does not pass instantaneously from the celestial bodies to the earth; but, in 1675, M. Roemer, whom we have before mentioned, found, from the observed times of the immersions and emersions of Jupiter's satellites compared with the times given by calculation from the laws of their movements, that the phenomena were accelerated or retarded by some cause which seemed to depend upon the variations in the distance of Jupiter from the earth; and this circumstance led him to conceive that the differences might arise from the unequal times in which light is transmitted from that planet to the eye of the observer; comparing, therefore, those differences with the corresponding distances of Jupiter, he calculated that a particle of light would pass through a space

equal to the diameter of the earth's orbit in about 11 minutes; subsequent comparisons of the observed and calculated times of other phenomena have proved the justice of the opinion, but it is now found that 8′ 7″.5 are required for the passage of light from the sun to the earth, and the velocity of light, hence determined, enters into the reduction of all observations relating to the planetary phenomena

The annual parallaxes of the planets, or the differences between the places they appear to occupy in the heavens when seen from the earth, and those to which they would be referred if seen from the sun, had long been known; and it was natural that efforts should be made to ascertain whether any such change of place was discoverable in the fixed stars these efforts have not indeed, to the present day, been successful; but, as those who dig for hidden treasures, if they do not find the immediate object of their search, at least derive benefit from the increased fertility they induce in the soil, so the observations instituted to find the parallax of the stars were productive of two important discoveries of another kind. Between the years 1660 and 1670 Picard had found, from many observations, that the star at the extremity of Ursa Minor, though it continually approached the pole by about 20 seconds annually, in consequence of the general precession of the equinoxes, yet suffered other changes in its distance from thence, being, in spring and autumn, further from the pole by several seconds than, according to the law of the precession, it ought to be; at the end of the year he found these variations compensated and, in the next, they re-occurred in the same order as before Similar variations of place were observed by Hook and Flamstead in several other stars, but it was presently perceived that these took place in directions contrary to those of the variations which would have resulted from the effects of parallax, and no solution could then be found, of the phenomena.

At length, in 1725, Molyneux and Bradley commenced a series of observations, with a zenith sector whose radius was 24 feet, on the star γ Draconis, which, passing the meridian nearly in the zenith of Kew, the place of observation, was, therefore, but little affected by refraction, the irregularities of

which might have been supposed to be wholly or partly, the cause of the variations observed in the star's place. The details of these observations are contained in the Philosophical Transactions for 1728, and from them it appears that the first observation was made in November 1725. the apparent place of the star in declination being then registered, Dr. Bradley repeated the observations at intervals, and found that the star constantly deviated towards the south, till, in the month of March, following, it was 20 seconds from its former place, and then it seemed to have attained its maximum of distance in that direction; for, from that time, it returned towards the north, and, in the month of June, its declination was nearly the same as when it was first observed: in the following three months, it deviated northwards from its first place as far as it had before deviated southward, and, at the end of a year from the commencement of the observations, its declination was again the same as at first. Similar deviations in right ascension were, subsequently, observed, and thus the star appeared to describe in the heavens, a small circle, annually, about its mean place. The regularity of the phenomena excluded the possibility that they could be caused by any errors in the position of the instrument; and Bradley, at first, thought they might be produced by that solar nutation which had been mentioned by Newton, but, on calculating its effects, they were found too small to account for the variations actually discovered; and finally, his investigations terminated in the discovery that the apparent variations of position were caused by the movement of light combined with that of the earth in its orbit, in a way which may be thus explained.

If the earth were at rest, and light from any star were transmitted instantaneously to the observer, it is evident that, on directing a telescope to the true place of a star, the latter would become immediately visible. But, if we suppose the earth to be in motion and light to be transmitted, in time, from one part of space to another, it would follow that, on directing the telescope to the true place of the star, the movement of the telescope would cause a particle of light from thence, in its passage down the tube, to strike against the interior surface of the latter, and,

as it could not then enter the eye of the observer, the star would be invisible. If, however, we suppose the telescope to be situated in a plane passing through the star and a tangent to the earth's orbit, and to be in a certain position between a line joining the earth and star and that part of the tangent which lies in the direction of the earth's motion; and, to avoid too great complexity, let us leave out the effect of the earth's rotation on its axis, by supposing the observations to be made when the star arrives on the meridian, then it may be conceived that a particle of light from the star, having arrived at the object glass, on continuing its motion from thence towards the earth, may, in consequence of the movement imparted to the telescope by that of the earth in its orbit, be constantly in the axis of the telescope till it arrives at the eye of the observer, and thus the pencil of rays falling upon the object glass, along with the above mentioned particle, will render the star visible: but the observer who determines the place of a celestial body by the direction of his telescope will, of course on that account, assign to the star a position which, when the cause of the error is understood, will be found to be in advance of its true place, and the deviation of the apparent, from the true place will, evidently, depend upon the proportion between the velocity of light and that of the earth.

As this deviation may be observed every time that the star arrives at the meridian of the place of observation, it is clear that, during one year, any star will appear to describe a circle, or rather an ellipse, in the heavens, parallel, and similar to the earth's orbit; but the apparent magnitude of the ellipse will depend on the above mentioned velocities and upon the position of the star with respect to the ecliptic; and, both by observation and calculation, it is found that the semi-axis major, when a maximum; that is when the star is in the pole of the ecliptic, subtends at the earth an angle of about 20¼ seconds; and this is the greatest difference, on account of the aberration, as it is called, of light, between the apparent and true places of a star. Hitherto we have been able to give no direct evidence of the movement of the earth, but this phenomenon being capable of an accurate explanation by supposing that movement, we are

bound, from thence, to consider the fact of the earth's motion as completely established

But Dr. Bradley continuing his observations on γ Draconis and other stars, in order to verify his theory of aberration, was so fortunate as to discover a new variation of their motion, which he found to depend on the place of the moon's node. for, from the year 1727 to 1736 he perceived that those stars, when near the colures, constantly approached the pole; the greatest difference between the observed places and those which would result from the general precession being about 9 or 10 seconds. The observations were afterwards continued till 1745, and, during the latter interval, the same stars appeared to recede from the pole by the same degrees as they approached it, and to an equal extent. Corresponding inequalities being observed in the right ascensions of the stars, Dr. Bradley found that the phenomenon might be represented by supposing the pole of the earth to make a revolution in the heavens about its mean place in the circle of precession, to which it returned at intervals of eighteen years. He, at first, thought the revolution was performed in a small circle, but more accurate observations shewed that the pole described an ellipse whose axes were equal to 19 seconds and 14 seconds, respectively.

This inequality was immediately perceived by Bradley, (and that astronomer published an account of his theory in the Philosophical Transactions of 1748,) to be caused by the action of the sun and moon, and, it may be added, of the planets, on the equatorial regions of the earth. The effect above described is, evidently, only that part of the whole variation, which depends on the attraction exercised by the moon, since its restitution takes place in the period of a revolution of her nodes, by which she is repeatedly brought to the same situation with respect to the earth's equator; and it is evident that the variations of her attractive force must, necessarily, produce corresponding oscillations in the position of the equator, alternately increasing and diminishing its obliquity to the ecliptic, and causing the equinoctial points to advance and retrograde, within small limits, about the points to which they would arrive in consequence of the general precession. The apparent oscillatory movement of

the pole of the earth, in declination, is the cause that the phenomenon received the expressive name of nutation; and the part of it which depends upon the attraction of the sun on the equator was, afterwards, distinguished from that which is dependent on the moon, but its amount is small and its restitution takes place yearly.

The discovery of aberration and nutation entirely delivered the fixed stars from the errors to which the observations made on them were, previously, subject, except such as depend on the proper movements of the stars themselves: these are fortunately very small, but, to reduce the cause of them to a system, will probably require the assiduous attention of astronomers for many ages to come.

The ancient philosophers, in their physical theories of astronomical refraction, seem to have supposed the atmosphere to be of uniform density; and though some notice is found, in the works of Alhazen, of the augmentation produced in the density of the air near the earth by the pressure of that above, yet it does not appear that any enquiry was made concerning the nature of the path described by a particle of light, in the atmosphere, till the seventeenth century; when the successive refractions in the different strata through which the light passed were supposed to cause each particle to move in the periphery of a conic section. Astronomers, however, at present, consider a particle of light, on entering each of the different strata, into which they imagine the atmosphere to be divided, from the surface of the earth upward, to be attracted from its previous course by a force proportional to the density of the stratum; and their conclusion is that the whole refraction, which had formerly been supposed proportional to the tangent of the zenith distance of the celestial body, simply, is proportional to that term lessened by about three times the value of the refraction itself.

The different temperatures of the air in different climates of the earth, which must necessarily produce corresponding variations in the density of the lower strata of the atmosphere, naturally induced an opinion that the value of the horizontal refraction was different, in different regions; and this seemed to

be confirmed by the observations of Richter, which indicated that the refraction at Cayenne was less than in the latitude of Paris. The long duration of twilight in the northern regions, has always been considered as a proof that the refractions are much greater there than in the temperate zone; and the same conclusion is drawn from the direct observations made by the Swedish mathematicians, according to which the horizontal refraction at Torneo is equal to above 52 minutes, while, in England and France, it does not exceed thirty-three minutes. The diminution of the refraction in the torrid zone is, however, rendered doubtful by the observations of Borda and Dr. Maskelyne, which seem to shew that, at equal altitudes, there is no sensible difference between the refractions in the West Indies and in this part of the world.

Besides the derangement produced in the places of all the celestial bodies by the curvature of the rays of light in the atmosphere, the situation of the observer is the cause of a difference between the apparent, and that which is considered as the true or geocentric place of the sun, moon or a planet; for the latter place, which is given by astronomical tables, being necessarily that to which the observed body would be referred by a spectator at the centre of the earth, cannot agree with the former, which is determined by observations made on the surface, except when the celestial body is in the zenith of the observer: the difference between the apparent and geocentric places is called the diurnal parallax, and, till the value of that which relates to the sun could be ascertained, it is evident that the absolute distances of the earth and planets from that luminary would be very imperfectly estimated. Of all the bodies in the solar system, the moon, however, being that which is nearest to us, is, on that account, the most affected by the above cause of error, and permits the value of the element to be determined with the most facility and precision. From the importance, therefore, of the lunar parallax in practical astronomy, considerable efforts have been made to obtain it by direct observations; but those which are considered as affording the most satisfactory results were made in the time of Bradley and La Caille, when the latter, at the Cape of Good Hope, and

the former, in conjunction with other astronomers, in the principal observatories of Europe, made, by previous agreement, corresponding observations on the moon at the same instant of time. These observations were simply, zenith distances of the moon, taken when she was on the meridian of each place respectively, and, afterwards, reduced to one common meridian; and as, in the northern and southern hemispheres, they are affected in opposite directions by the parallax, it was easy to determine this element from the observations: the horizontal parallax of the moon, for Paris, was, thus, found to be 57′ 39″, and that at the equator, from the spheroidal figure of the earth, was, from thence, by computation, found to be 57′ 11″.4, at the mean distance of the moon from the earth; and consequently, that mean distance may be considered equal to 60.1054 semidiameters of the latter The horizontal parallax being known, the parallax corresponding to any given altitude of the moon can be easily found. About the same time the moon's parallax was determined by computing the versed sine of the arc she describes in one second of time, from the proportion it bears to the assumed distance of the moon from the earth, and by comparing it with the space which a body, in the same time, describes, by gravity, near the latter., the spaces descended by the moon and any body near the earth being inversely as the squares of their distances from the centre of the earth, the ratio between the semidiameter of the latter and the distance of the moon, becomes known; and, hence was obtained the equatorial horizontal parallax, which was found to be 57′ 12″.34, when the moon was at the mean distance, and which agrees very nearly with the value found by observation.

By a process similar to that which has been above mentioned, La Caille at the Cape of Good Hope, and Wargentin at Stockholm, places which have nearly the same longitude, obtained, in 1751, from the simultaneously observed zenith distances of Mars, and his distance from a given fixed star, the horizontal parallax of the planet, when in opposition, and found it equal to 22″. 9. Such a process, however, is quite inapplicable to the determination of the parallaxes of the sun and of the other superior planets; the smallness of that element rendering it inse-

parable from the errors of the observations: but it had been, previously, proposed to ascertain the diurnal parallax of the sun indirectly, from the transits, which occasionally occur, of the two inferior planets over that luminary; and Venus, being that which, at her inferior conjunction, is the nearest to the earth, was particularly proposed as the most convenient for this important purpose.

The transits of Mercury frequently occur; the first of which any account has been given was observed by Gassendi in 1631; and it is due to the memory of Shakerlaus to record that, from his attachment to astronomy, he made a voyage, in 1651, to Surat purposely to see one there, which was invisible in Europe, and that he lost his life in Persia on his return. Dr. Halley, in his voyage to make observations in the southern hemisphere, also obtained, at St. Helena, a complete view of the transit of Mercury in 1677; and it was while employed in this service that he proposed the two transits which were to occur in 1761 and 1769, to be observed, for the purpose of ascertaining the sun's parallax and his distance from the earth; both of which elements would thereby, he expected, be determined extremely near the truth.

We have mentioned the transit of Venus observed by Horrox and Crabtree, in 1639, but the circumstances attending the observation were too unfavourable to allow the computations founded on it to be entirely depended on; the transit of 1761, though diligently observed in various parts of the world, also failed from the want of harmony between the several results obtained from it, but that of 1769 was more fortunate; since the observations, when reduced, gave, for the sun's parallax, values between the limits of 8″. 5 and 8″. 8; which, however, do not differ much from that obtained by Mr. Short, from his observations of 1761 [a]. The last of the two limits, which was determined by Dr. Maskelyne, is by Delambre considered rather too great, but it is admitted that the error is probably less than a quarter of a second.

The data to be obtained from the observations of the transit

[a] Philos. Trans. 1763.

over the sun's disc were the times of the immersion and emersion of the planet; but these were to be observed at two or more places on the earth's surface, where the duration of the transit would be the most lengthened and the most shortened, respectively, by the effects of parallax; and, that these conditions might be fulfilled, the places chosen were, besides the sites of the principal observatories in England and on the continent, Lapland and Kamtchatka, in the north; St. Helena, the Cape of Good Hope and the Society's Islands, in the south, and India, near the equator; and to these, astronomers were sent by the different sovereigns of Europe, who honourably joined in patronising a work which was justly considered as of high importance to the interests of science.

To give a brief indication of the nature of the problem for finding the sun's parallax from the transit of Venus, we may state that, if the contact of the planet with the exterior or interior edge of the sun's disc were observed, the sum or difference of the semi-diameters of the sun and planet, taken from the tables, might be considered as the hypotenuse of a right angled plane triangle whose two sides are, respectively, the difference of longitude and difference of latitude of those celestial bodies, (these differences being first computed from tables, for the time of observation, as if seen from the centre of the earth, and reduced to the values they should have when seen from the surface by applying the algebraic expressions for the unknown difference between the parallaxes,) then, making the sum of the squares of these sides equal to the square of the hypotenuse, the equation thence resulting will serve to determine the said difference of the parallaxes. But, the relative distances of the sun and Venus from the earth being already known, the ratio of their parallaxes is known; since the parallaxes are inversely proportional to the distances, and the separate values of two quantities can be found when we know their differences and the ratio between them: thus the parallaxes of both the sun and Venus were obtained. The computed longitudes, latitudes and semi-diameters of the two bodies being, however, affected by the unknown errors of the tables as well as by the parallaxes, it became necessary that several observations should be made in

order that there might be obtained a sufficient number of equations to determine all the unknown quantities: and, from the above named value of the sun's parallax, 8″. 8, the distance of the sun from the earth is found to be equal to 23465 semi-diameters of the latter.

The eighteenth century is become celebrated, also, for the improvements made in telescopes and in the instruments employed for the purposes of nautical astronomy. The field of view, in the telescopes which had been in use before the middle of the century, was unavoidably small, and the illumination of the object consequently feeble, on account of the apparent distortion of the image, and the coloured fringes with which it was surrounded, when the aperture of the instrument was extensive enough to allow the admission of as much light as would render the object sufficiently brilliant; but, in 1757, Mr. Dollond, guided by the theories of Euler and Clairaut and by his own experiments on lenses formed of glass possessing different degrees of refractive power, invented, or at least made public, a construction in which the chromatic aberration, as it was called, was almost wholly removed, and the spherical aberration materially diminished. These ends were gained by forming a compound object glass consisting of a convex and concave lens having different degrees of dispersive power with respect to rays of the different colours, these being separated from each other in their passage through the glasses, whose surfaces act upon the light like those of a prism: in such compound lens, by a proper adaptation of the focal lengths of the two glasses, the rays of the different colours could be made to unite nearly in the place where the image is formed; and thus the latter was rendered sufficiently free from the colours with which, in the old construction, it was embarrassed. By a just adaptation of the curvature of the surfaces of the object glasses, and by dividing the whole refraction of the light coming from the image in the focus, among the four different eye-glasses of the telescope, the distortion of the image was also, nearly, corrected: and thus greater magnifying power and perfection of vision was obtained.

From that time scarcely any improvement can be said to have

been made in what are called, from the absence of the prismatic colours, achromatic telescopes; but the telescopes formed with metallic specula have undergone several changes, and the instruments of this kind, constructed by the late Sir William Herschell, far exceeding in magnifying power any of those formed wholly with glass lenses, have contributed materially to increase our knowledge of the constitution of the heavenly bodies.

In 1731, Mr. Hadley, the ingenious contemporary of Bradley and Molyneux, pursuing a principle which had been proposed by Newton, brought to a state of great perfection the reflecting octant and sextant, by which the altitudes of the sun, moon and stars, and the angular distances between them have ever since been measured for the purpose of obtaining, by celestial observations, the latitude and longitude of a ship at sea, or of a place on land, where the instruments employed in regular observatories are not to be had. A considerable change, however, has since taken place in instruments of this nature by making them completely circular, and capable of measuring the angle between the objects many times successively, in consequence of which the greatest correctness may be obtained. Mayer, of Gottingen, in 1758, first constructed such repeating circles, as they were called, and they have since been much improved; but that kind which possesses the highest character for accuracy was made public by the chevalier Borda, in 1789.

It appears from a report made by Newton, in 1714, to a committee of the House of Commons, on a method proposed by Whiston for finding the longitude of a ship at sea by the place of the moon, that the theory of the latter was not, then, accurate enough to determine that element within less than two or three degrees of the truth: but, in proportion as improvements were made in the instruments of observation, the inequalities of the moon's motions were more correctly determined; and Mayer, who had diligently applied himself to this branch of astronomy, succeeded in constructing a set of lunar tables from which the distance between the sun, or a star, and the moon, could be computed for any given time with sufficient correctness to become capable, by comparison with the observed distance, of

serving in the determination of the great problem of terrestrial longitude. These, and a set of improved solar tables, were published by Mayer in 1770; he did not, however, live to enjoy all the fruits of his labours, but his widow received from the British government the reward which it had previously offered to any one who should bring the tables to the required degree of accuracy. Since this period, therefore, the distances between the moon and sun, and between the moon and certain fixed stars have been computed for every three hours in each day, as they would appear at the places of some of the principal observatories in Europe, and are published in the Astronomical Ephemerides for years in advance; so that, by comparing them with the distances actually observed in other places, the difference between the corresponding time given in the Ephemeris and that found at the place of observation, which expresses the difference in the longitudes of the two places, is immediately found. This is not all the advantage derived from the publication of these Ephemerides; in them are also given, besides many other articles of great value to the practical astronomer, the times of the immersions and emersions of Jupiter's satellites, by which a scientific traveller, on land, (for the method is not practicable at sea on account of the motion of the ship,) observing the same phenomena in a telescope of sufficient magnifying power, can, also, determine his longitude by a comparison of the time found at the place of observation with that given in the Ephemeris.

But, to these means of facilitating the solution of that useful problem, must be added the perfection attained in the constructions of instruments for measuring time. In 1764, Harrison completed a chronometer which, having been taken across the Atlantic, and being found on its return to have deviated from the true time only 54 seconds, in an interval of 156 days, was considered as having fulfilled the conditions required to entitle the maker to the reward offered by government for a machine capable of keeping time with sufficient accuracy to serve for finding the longitude at sea; the promised sum, [£10,000,] was, consequently, paid to the ingenious mechanic, and the

use of chronometers, for that purpose, by nautical men, during long voyages, has ever since been general. A seaman, therefore, previously to his departure from the British shores, has only to set the index of the machine to the actual instant of mean time on the meridian of the Greenwich observatory; and, in any part of the world, however remote from thence, if he find his time by celestial observations, his distance, in longitude, from that meridian, will be expressed at once by the difference between the time thus found and that shewn by the chronometer.

CHAPTER XXII.

OPERATIONS FOR DETERMINING THE FIGURE OF THE EARTH.

An arc of the terrestrial meridian measured in France by Picard and Cassini.—The terrestrial spheroid supposed at first to be prolate.—Proof of the diminution of gravity in the equatorial regions.—Arcs of the meridian measured in Lapland and Peru.—The figure of the earth proved to be oblate.—Trigonometrical operations in England.—Arcs of the meridian measured in various parts of the world.—Great geodetical operations in France and Spain.—Experiments of Captain Sabine on the lengths of pendulums.—Ratio of the earth's equatorial and polar diameters.—Effects of local attractions in geodetical and astronomical observations.

In the time of Newton the question of the dimensions and figure of the earth particularly engaged the attention of mathematicians, and several efforts were made to determine both, by ascertaining, and comparing together, the lengths of certain portions of the terrestrial meridian. The attempts of the ancient Greeks and Arabians to acquire a knowledge of the earth's magnitude have been already mentioned, and we may observe that similar attempts had, just before the time of which we are speaking, been made by Ricciolus, Fernel, and Snellius, on the continent, and by Norwood in England; but from their labours no satisfactory conclusion could be obtained, on account of the inaccuracy of their itinerary measurements. At length, about the year 1670, the French Academy of Sciences engaged Picard to determine the distance, in the direction of the meridian, from Malvoisine to Amiens, by means of a measured base line, and a series of triangles formed between those places. This base was made a side of one of the triangles, and the angles of all the triangles being taken with instruments, the lengths of the several sides were computed, from which, with the observed azimuths, or bearings of the sides from the meridian, the corresponding arcs of the meridian were found: finally, comparing the length of the whole arc with the difference, in latitude, between its

extremities, it was found that the length of a degree of the meridian, in that district, was 57060 toises. The arc of the meridian measured by Picard was afterward, by Dominicus Cassini, extended from Amiens to Perpignan, towards the south, and by Jaques Cassini, in 1713, from Amiens to Dunkirk, northward; and the lengths of the different degrees of latitude within this extent being separately ascertained, it was found that they diminished in going from north to south, a circumstance which indicated that the polar diameter exceeded, in length, the equatorial diameter of the earth, or that our planet had the form of a prolate spheroid: this indication appeared, subsequently, to be confirmed by the results which Cassini de Thury obtained from the measurement of the length of a degree of longitude in the parallel to Brest, for this was found to be shorter by 781 toises than it should have been if the earth were a perfect sphere; and, if such had been the fact, it would also have followed that the earth was elongated in the direction of its axis. Hence arose, in France, a prejudice in favour of this opinion, which was not easily removed, and which operated strongly for a time to retard, on the continent, the acquiescence in the Newtonian theory of gravitation; because, from the latter, as we have seen, in consequence of the earth's rotation on its axis, it should have been found that the equatorial, is longer than the polar diameter, or that the earth is an oblate spheroid. While the opinion prevailed that the polar diameter was the longest, there were not wanting philosophers, like Mairan, in France, who believed that they had discovered a physical reason for it, though it is now known to have had no other foundation than the inaccuracies of the observations and admeasurements; it is, however, but fair, to say that, when the error was detected, it was with the utmost candour acknowledged, and ample justice was rendered to the sagacity of the English philosopher whose theory now, daily, received additional confirmation from the agreement between the consequences drawn from it and the results of operations then constantly carried on with superior diligence and care.

A proposal having been made in the French Academy to ascertain the parallax of Mars, at the time of his opposition to the sun, by his distance from a certain fixed star observed at the

same instant in two places, considerably distant from each other, on the earth; with a view of computing, from thence, the value of the sun's parallax and the distances of the planets from that luminary; M. Richter, one of the members, was appointed to proceed to Cayenne in order to make there the necessary observations, simultaneously with those which were to be made at Paris, and was furnished with a pendulum clock for the purpose of obtaining the right ascensions of stars by their transits over the meridian: on comparing together the times of the transits of particular stars on successive nights, this astronomer was surprised to find that the pendulum, which had been carefully regulated according to mean time at Paris, made, in one day, at Cayenne, a number of vibrations less by 148 than it made at the former place, or that the movement of the clock was too slow, daily, by 2′ 28″; so that, to cause the pendulum to make the same number of vibrations at both places, it was found necessary, at Cayenne, to diminish its length by above one tenth of an inch. Now, as the effect was too great to be considered as arising from the expansion of the rod by heat, or from a greater resistance of the air in those regions, no other conclusion could be drawn from it than that the force of gravity was less near the equator than in France; and though, at first, some doubt prevailed concerning the justness of this conclusion, because it was supposed possible that the difference in the time of a vibration might be owing to some local cause; yet when, soon afterward, similar results were obtained from observations, made expressly for the purpose, in other parts of the world, it was readily admitted that the fact, in accordance with the Newtonian theory, amounted to a satisfactory demonstration that the equatorial, was longer than the polar diameter of the earth; in consequence of which, terrestrial bodies at the surface of the latter, in the equatorial regions, being further from the centre than in France, were less powerfully attracted by gravity, and more affected by the centrifugal force arising from the earth's daily rotation on its axis.

But the limits of France were, evidently, insufficient to allow any conclusive argument concerning the figure of the earth to be drawn from the variations in the lengths of the degrees of latitude measured in that country alone; and the desire of ob-

taining data from more extensive operations induced the French Academy to send some of the distinguished men who were then associated with that learned body to the torrid and frigid zones for the purpose of ascertaining, by their admeasurements, with more precision, the proportion between the equatorial and polar diameters of the earth; the length of a degree measured in one of those regions compared with that of a degree measured in the other, necessarily, presenting a much greater difference than can exist between two degrees measured in any one country. In 1735 M.M. Maupertuis, Clairaut and Lemonnier proceeded to Lapland and, at the same time, M.M. De la Condamine and Bouguer sailed to Peru to fulfil the objects of their respective missions; the former party was joined by M. Celsius, a Swedish philosopher; and the latter, by the Spanish mathematicians Don George Juan and Don Antonio di Ulloa; and each party, labouring for its own glory as well as for the interests of science, prosecuted its operations with singular zeal and assiduity. That in the north encountered, as may be expected, vast difficulties from the nature of those frozen regions, a base, however, was measured upon the ice of the river Torneo, the mercury in Reaumur's thermometer being at 37 degrees below the freezing point, and a series of triangles was extended, from the city of that name, to Pello, towards the north, including an arc of nearly one degree; and the result of the operations was that, in the seventy-sixth degree of latitude, the length of a degree on the meridian is equal to 57438 toises. The measured arc of the meridian in Peru extended along the valley of the Cordilieres, from Cotchesqui, nearly under the equator, to Tarqui towards the south; and the difference of latitude between the two extremities of the arc was rather greater than 3 degrees: the operations cost the labour of eight years, and the length of a degree at the equator was found to be equal to 56753 toises [=60484·5 English fathoms].

On the return to Paris, of the mathematicians who had been engaged in these distant and laborious surveys, a comparison was made of the results they had obtained; and the earth's compression at the poles was determined from the lengths of the degrees of latitude in the several places: considerable

differences, however, were found in the values of the compression, but the fact itself was fully confirmed. The degree in Peru compared with that in France gave, for the ratio of the equatorial to the polar diameter, 304 to 303; the former degree compared with that in Lapland, gave 211 to 210; while, according to the theory of gravitation, the earth being supposed homogeneous, it should have been as 231 to 230. But some doubts having been raised about the accuracy of the base line, measured in Lapland, the length of a degree in that country was, by M. M. Swanberg and Offerbom, re-measured in 1801, nearly on the site of the former operations but, upon an arc of greater extent, and found to be equal to 57196 toises, [=60956 6 English fathoms,] or about 242 toises less than it had been before made; and this new measure, being compared with that of the degree in Peru, gave the ratio of 334 to 333 for that of the earth's diameters.

In 1783, the government of France, at the recommendation of M. Cassini de Thury, proposed to that of England to unite the geodetical operations then in progress, in the former country, with corresponding operations in this, for the purpose of determining with accuracy the difference of longitude between Greenwich and Paris; and the proposal, being accepted, was immediately put in execution, under the direction of General Roy who, having measured a base on Hounslow Heath, extended a series of triangles from thence to the coast of Kent, where it was connected with the series formed between Paris and the opposite shores of France: a detailed account of these operations was published in the Philosophical Transactions; but the plan first adopted by government was, afterward, enlarged, and a complete trigonometrical survey of Great Britain was executed chiefly under the direction of General Mudge who, in the course of the proceedings, in the years 1800, 1 and 2, measured, between Dunnose in the Isle of Wight and Clifton in Yorkshire, an arc of the meridian including nearly three degrees of latitude, from which it was found that the length of a degree, in lat. 52° 50′ 30″, is equal to 60766 English fathoms; and in lat. 51° 2′ 54″, to 60884 fathoms[a]. Colonel Colby was subse-

[a] Operations for a Trigonometrical Survey of England by Mudge and Dalby.

quently associated with General Mudge and, after the death of the latter officer, he had the sole direction of this great national undertaking

The latter part of the eighteenth, and the beginning of the nineteenth centuries form a period celebrated for the geodetical operations which, nearly at the same time, were carried on in different parts of the world; besides the measurements in France and England, Peru and Lapland, of which we have spoken, the length of a degree was determined near Rome, by Boscovich and Lemaire; in Pennsylvania by Mason and Dixon In 1751, La Caille measured one at the Cape of Good Hope, and, between the years 1802 and 1810, Major, afterwards Colonel Lambton executed a similar operation on the coast of Coromandel The operations in Pennsylvania, on account of the nearly level state of that country, consisted in simple measurements made actually in the direction of the meridian through a great portion of the arc, which included about 1½ degree of latitude, the length of the degree, its middle point being in 39 degrees north latitude, was found to be 60628·5 English fathoms. The degree measured at the Cape, in 33° 18′ south latitude, was made equal to 57040 toises [=60790 4 English fathoms,] and the arc in India, which extended between 8° 9′ 38″ and 14° 6′ 19″ north latitude, gave 60496 English fathoms for the length of a degree whose middle point was in 10° 34′ 49″ north latitude, and, on comparing this length with that of the degree determined by Mudge for 52° 2′ 20″ north latitude, Colonel Lambton found the ratio of the earth's axes to be as 329 to 328 [a]. But the above works are eclipsed by the immense operations carried on in France between the years 1791 and 1808, these, which were determined upon by the French academy in the midst of the troubles caused by the revolution, were undertaken for the double purpose of ascertaining the precise length of a degree of latitude in that country, and of obtaining the value of a standard for measures of length, which should be invariable, by being made to bear a certain proportion to the circumference of a meridian of the earth A base was, therefore, measured at Melun, near Paris, and

[a] Asiatic Researches, vols. viii., x, and xii.

the series of triangles was extended, by M.M. Mechain and Delambre, to Dunkirk and Barcelona: such was the accuracy of the work that the length of a base of verification, which was measured near Perpignan, at 400 miles from the first base, being compared with its computed length, as a side of one of the triangles, the difference was found to be less than one foot[a]. The length of the degree, determined from that of the computed meridional arc, was 56977·8 toises, [=60724 English fathoms,] in the latitude of 44° 41′ 48″, and this, compared with the length of the degree in Peru, gave the ratio of 334 to 333 for that of the earth's equatorial and polar diameters[b]. M.M. Biot and Arago, being joined by two Spanish mathematicians, subsequently prolonged the triangulation as far as the island Formentera in the Mediterranean, and, after great difficulty, arising from the small light afforded by the mirrors of the lamp at the distance from thence to the coast of Valencia, they succeeded in fixing the island as the southern extremity of the arc[c]. M. Biot in conjunction with the English mathematicians finally continued the triangulation, towards the north, as far as the island of Unst, one of the Hebrides which, then, became the limit of the arc in that direction The difference of latitude between Dunkirk and Formentera is 12° 22′ 13″ and, from the length of this portion of the terrestrial meridian, its circumference is computed to be 24855·42 English miles: one forty millionth part of this circumference is equal to 39 378606 English inches, which is the value of the unitary measure of length now employed in France. Commissioners from various countries met in Paris, in 1798, to decide on the question of the figure of the earth from the data afforded by such trigonometrical operations as had been, then, completed; and we cordially join with a French writer in regretting that political circumstances should have prevented the country of Newton from being represented in an assembly of learned men convoked for the purpose of deliberating on a subject of such importance to all the civilised world[d]

[a] Base du Systême metrique par Delambre

[b] Delambre, Astronomie Theorique et Pratique, Tom. III.

[c] Notice sur les operations faites en Espagne, par M. Biot.

[d] Voiron, Histoire de l' Astronomie, troizième partie.

During the performance of these great works, observations were made both in France and England, at several of the stations determined by the surveys, on the length of the pendulum vibrating seconds, for the purpose of ascertaining the figure of the earth by the intensity of gravity at different points on its surface: and it is pleasing to observe that, in furtherance of this useful object, the British Government, afterward, contributed largely by appointing Captain Sabine to make similar observations at several places beyond the seas: this distinguished officer, in 1822, sailed in the Iphigenia to Sierra Leone and the island of St. Thomas, from whence he proceeded to Bahia in Brazil; and returned to England by the way of Jamaica and New York, and, at all these places, besides experiments relating to the intensity of terrestrial magnetism, he made many observations on the number of vibrations performed by a pendulum of invariable length in given times. The instrument was of the kind recommended by Captain Kater, having its centres of suspension and oscillation convertible, by which a very accurate measurement of the interval between them could be made, and the length of the seconds' pendulum, consequently, could be easily deduced. In the following year, Captain Sabine sailed, in the Griper, to Norway, Greenland and Spitzbergen, for the like purposes, and thus, the observations were extended from the equator to a point as near as possible to the pole: from a careful discussion of all, it was found that the length of the equatorial pendulum vibrating seconds is equal to 39·01568 English inches, and that the force of gravity at the pole is, to that at the equator, as 1·20213 to 1, from whence the ratio of the equatorial to the polar diameter of the earth is shewn to be as 289 to 288 [a]: and it is worthy of remark that this agrees very nearly with the ratio determined by La Caille from observations of a like nature made, between the years 1751 and 1755, at the Cape of Good Hope, in the Isle of France, and at Paris

The values of the degrees of latitude found at different places on the earth's surface differ from each other more than might be expected, considering the great attentions that have been paid, to

[a] Account of experiments to determine the figure of the earth, by Edward Sabine.

ascertain and make allowance for every known cause of error. In France, the lengths of the degrees were found to go on diminishing from north to south but not in a regular progression, in England, on the contrary, they were found to diminish from south to north, so that, if the figure of the earth were to be deduced from the degrees in the former of these countries alone, it would appear to be oblate; if, from the degrees in the latter, it would appear prolate · but it was never supposed that the figure could be ascertained from the lengths of a few degrees contiguous to each other and, therefore, this opposition of results is not to be considered as militating against the conclusion drawn from a comparison of the degree in Europe with those in India and Peru, which decidedly establishes the fact of a compression at the poles. Not only, however, do the lengths of degrees measured in the northern hemisphere of the earth deviate, within certain small limits, from the values they should have on the surface of a regular spheroid, but the degrees measured in corresponding latitudes in the opposite hemispheres also disagree; now, two opinions only can be formed concerning these discrepancies, and both are very probably correct, one is, that the form of the earth is neither that of a regular spheroid nor ellipsoid, and the other, that local attractions, which it is difficult or impossible to estimate accurately, derange the plumb-lines of the instruments by which, in order to ascertain the latitudes of the stations, the zenith distances of stars are measured. The proportions between the equatorial, and polar diameters of the earth are, necessarily, various, we have said that the comparison of the arc measured in France with that in Peru, in which last it should be remarked that the observations of Bouguer were made use of, gives, for that proportion, 334 to 333; but M. Delambre, taking a mean of the observations of Bouguer and La Condamine, afterwards found it to be as 309 to 308. We have said, also, that the length of a degree in India, compared with that in England, shewed the ratio to be as 329 to 328; but one of the former degrees, being compared with those measured in England, France and Sweden, produced, for a mean result, the ratio of 318 to 317; and, probably, a mean of the ratios above assigned by Delambre and Lambton, which would

be as 314 to 313, may be taken as that of the greatest and least diameters of a regular spheroid coinciding as nearly as possible with the true figure of the earth.

M. Bouguer was the first who found, by the changes it was necessary to make at different places, in the length of the pendulum vibrating seconds, that the force of gravity diminished more rapidly, in proceeding towards the equator, than the spheroidal figure of the earth and the increase of centrifugal force gave reason to expect; and he was led to imagine that the lateral attraction of the mountains, on the pendulum, might be the cause of the difference: to ascertain this point, he took the zenith distances of certain stars, the instrument being placed on the side of Chimboraço, and he perceived indications that the plumb-line deviated about $7\frac{1}{2}$ seconds from the vertical position, but, as the smallness of this quantity rendered its accuracy doubtful, the mountain, from its size, seeming likely to cause a greater deviation, Dr. Maskelyne was appointed, in 1774, to make a series of observations in the neighbourhood of the Schehallion, a mountain in Perthshire, with a view of deciding the question. for this purpose, with a sector whose radius was 10 feet, he observed the latitudes of two places on opposite sides of the mountain, and, on comparing the difference between them with that determined by geodetical operations, it was found that the plumb line had really been attracted in contrary directions at the two stations, and that each deviation amounted to 5″ 8[a]. Besides the result thus obtained, Dr. Hutton found that the density of the whole earth is to that of the mountain as 9 to 5; and Professor Playfair, who had determined by direct experiment that the density of the latter is to that of water as 2 75 to unity, concluded that the mean density of the earth is nearly five times as great as that of water; a result which differs but little from the determination of Newton. No doubt, then, can exist that local attractions, arising from inequalities on the surface, and the want of homogeneity in the mass of the earth, influence materially the directions of the plumb-lines by which the zenith of the observer is ascertained, and, consequently, much uncertainty must prevail concerning the latitudes of the places which mark the limits

[a] Dr. Hutton's Tracts, Vol II. Tract 26.

of the measured arcs of terrestrial meridians. General Mudge accounts for the remarkable variations in the lengths of the degrees measured in England by supposing that his plumb-line was made to incline towards the north, at all the stations, by attractive forces, which augmented in intensity in going from south to north; and it is easy to conceive that such attractions may be, partly, the cause that the experiments made on the vibrations of pendulums in different places, for determining the ratio of the equatorial, to the polar diameter of the earth, give results disagreeing with each other and with those obtained from geodetical admeasurements. Fortunately these differences are small in value, and it has been with justice observed, that our present knowledge of the form and dimensions of the earth is quite sufficient for any of the most delicate operations of astronomy, geography, or navigation.

CHAPTER XXIII.

THE LATEST DISCOVERIES IN THE HEAVENS.

Herschell's remarks on the solar spots.—Opinions concerning the state of the moon's surface.—Discovery of the Georgium Sidus.—And of the four new planets.—Notices of some ancient comets.—The orbits of comets suspected by Cassini to be curves returning into themselves.—Dr. Halley computes the elements of a comet's orbit.—Uncertainty of the computations founded on the observed places of comets.—The knowledge of the fixed stars is yet imperfect.—Changes observed in the appearances of the stars.—Opinion of Sir W. Herschell concerning their proper motions.—Observed movements in the double and multiple stars.—Opinion of Herschell concerning the nebulæ.—An idea of Kepler concerning the distributions of the fixed stars.—Catalogues of stars.

THE highly improved state of the instruments employed in making celestial observations, and the diligence exercised by the illustrious men who, during the eighteenth, and in the beginning of the nineteenth centuries, devoted themselves to the cultivation of astronomy, while they brought to light many facts relating to the constitution of the bodies which compose our system, were the means of greatly extending, if we may so speak, the regions subject to the dominion of the sun, and of augmenting the number of planets and comets which, like vassal princes, own the influence of his power. The nature of the spots which occasionally appear on the sun himself were attentively examined by Sir W. Herschell, during several years, with the finest telescopes in existence, and his observations have led him to the conclusion that they are caused by an elastic gas, which, issuing from the solid matter composing the body of the sun, piercing the luminous strata surrounding it, and dispersing itself every way about the orifice, permits the dark nucleus at the bottom of the perforation to become visible to a spectator on the earth, when the latter is in the direction in which the perforation has been made; at times, also, Sir William was able to look obliquely down the opening and distinguish by a difference of colour, on the side opposite to the eye, the direction of the thick-

ness of the luminous mass. The elasticity of the gas appears, frequently, insufficient to allow the particles to make their way through the matter which surrounds the sun, and then it swells it into ridges or nodules, appearing more brilliant than the rest of the surface, or, escaping in small quantities, it disturbs the upper surface only, causing gentle swellings or shallow indentations; the last of which are rather more obscure than the other parts of the sun, and contain many small dark points, like pores, through which some of the ascending gas has passed.

The objects which diversify the visible disc of the moon have not been so minutely distinguished as might be expected from the magnifying powers of our telescopes: though the nearest to us of all the celestial bodies, she is still too remote to afford any indication of the productions of nature on her surface which, to judge from its appearance, should be as well fitted for the support of vegetable and animal life as the earth itself. Her mountains, occasionally, are disposed in chains or groups, like the Alps and Pyrennees, and rise to the height of five miles, nearly; but, more generally, they assume the appearance of annular ridges enclosing spaces, from 1800 to 16000 feet deep, like the beds of lakes or seas, or the craters of volcanoes long since extinct: frequently an isolated mountain rises from a plain, with portions of rock projecting from its sides, and round its base are scattered fragments which seem to have been separated by time from the principal mass. The absence of those variations of light and shade which would be produced by clouds floating above her surface, and the irregularities of the ground, visible at the bottom and on the sides of her cavities, have given reason to believe that no atmosphere surrounds her and that she is destitute of rivers and seas. Such are the opinions generally entertained concerning the moon, but M Schrœter, a German astronomer, ventures to assert that our satellite is the abode of living and intellectual beings: he has perceived some indications of an atmosphere which, however, he admits, cannot exceed two miles in height, and certain elevations which appear to him to be works of art rather than of nature. He considers that a uniformity of temperature must be produced on her surface by her slow rotation on her axis, by the insensible change from day to night, and the attenuated state of her atmosphere, which is

never disturbed by storms; and that light vapours, rising from her valleys, fall in the manner of a gentle and refreshing dew to fertilize her fields [a].

To this astronomer we are indebted for some observations on the figure and appearances of Mars, and for a knowledge of the times in which Venus and Mercury perform their revolutions on their axes, previously to his time, the rotation of Venus had been uncertain, and that of Mercury quite unknown, but, in 1793, Schrœter discovered both, from the recurrence of like appearances at the cusps of the planets when nearly in conjunction with the sun

In 1781, the attention of Sir William Herschell was first attracted to a star, in the constellation Gemini, which appeared to be larger and less bright than the rest, and, continuing to observe it during a few nights, he found that its place in the heavens gradually changed as soon as this circumstance was communicated to the learned, the principal astronomers of Europe made the star the subject of their nightly observations, and being satisfied that it was really in movement, they applied themselves to the consideration of its nature. At first, it was generally thought to be a comet, and attempts were made to compute the figure of its path on this supposition, but M. Lexell, of St. Petersburgh, discovered that it revolves about the sun in an orbit which is circular or nearly so, and that its distance from the sun is about twice as great as that of Saturn; and La Lande computed that the period of its revolution is about eighty-two years. These determinations being confirmed by all subsequent observations, the star newly observed was acknowledged to be a planet and received the name of Uranus, of Herschell, or, in honour of the reigning monarch, of the Georgium Sidus, the last of which, only, has been adopted in this country Within a year from its discovery, La Place, by means of several excellent observations, ascertained the ellipticity of the orbit, its principal elements, and the perturbations to which it is subject by the attractions of Jupiter and Saturn, and it is worthy of remark that, among these, he found two, pro-

[a] Voiron, Hist. de l'Astronomie.

ducing equations of its mean motion, not exceeding two minutes and a half of a degree, of which one is accomplished in 90 years, and the other in 569 years. This, as Voiron observes [a], is an astonishing proof of the power of analysis, by observation alone the variations in the movements of the planet could not be ascertained till after long periods of time, and in proportion as they became sensible to the observer, but the eye of the mathematician penetrates into the depths of ages to come, and, besides foreseeing several other inequalities, it is enabled to discover a correction of its mean motion amounting to the small quantity above mentioned, and compensated, periodically, in above five hundred years. The power of Herschell's telescope made known, between 1787 and 1794, that the planet was accompanied by six satellites, two of which are remarkable for having the planes of their orbits nearly perpendicular to that of the planet. On examining the registers of M. Le Monnier for the year 1765, several positions of a newly observed star are there found marked, which, from the subsequent determinations of the places of the above planet, shewed the star and planet to be the same; and it is evident, therefore, that if the French astronomer had taken the trouble to compare together his own observations, he would have anticipated Dr. Herschell in the discovery which has rendered the latter so justly celebrated.

From the days of Kepler it had been suspected, on account of the disproportion which the interval between Mars and Jupiter bears to those between the other planets, that a planet might exist in that interval; and this notion was thought to be verified when, in 1801, M. Piazzi, at Palermo, observed a small star, in Taurus, which was moveable, the star was, afterward, lost in the sun's rays, and was not again discovered till January in 1802, when the fact that it was a planet was fully ascertained. To this the name of Ceres was given, and the elements of its orbit were presently determined; it presented, however, this peculiarity, that the inclination of its orbit to the ecliptic was far greater than that of any other planet, being found to vary from 11 to 18½ degrees. But the supposed order of the distances of the

[a] Ut suprà.

planets from the sun, which seemed to be established by the discovery of this last, was soon found to be deranged, for, in 1802, Dr. Olbers at Bremen announced the discovery of another, which he named Pallas, in 1804 M Harding, at Lilienthal, discovered a third, to which he gave the name of Juno; and, lastly, in 1807, Dr. Olbers had the honour of discovering a fourth, which he called Vesta. As all these are found to be of very small magnitude, compared with the other planets, and to describe orbits nearly at the same distance from the sun, Dr. Olbers conceived that they might be the fragments of some great planet which, formerly, revolved about the sun in an orbit situated nearly in the same part of space, but which had been destroyed by some internal convulsion.

The attention of the learned in astronomy will, probably for ages to come, be particularly engaged in enquiries concerning the nature and movements of comets; these being the only bodies of our system which have hitherto in some degree defied the powers of modern science, it may be expected that they will become the objects of many nightly vigils in open air and many laborious researches in the closet. The comets are already known to partake, in some measure, of the nature of planets, but the persevering industry of man will impel him to multiply his observations, and renew his investigations in every direction till he shall have learned how to determine with precision all the elements of their orbits and till, fulfilling the prediction of Seneca in all its extent, he shall have demonstrated that both planets and comets are, in every respect, similar parts of the system to which the sun is a common centre of light, heat and movement.

The times in which these occasional visitants were considered as tokens of the Divine displeasure have long since passed away; and an intellectual age has justly classed that opinion with the other dreams of an idle and degrading superstition. yet, such are the disadvantages attending an imperfect knowledge of the phenomena of nature, that, when the comets were found to be masses of a material substance, and their paths were perceived to lie among the planets, the terror they had inspired changed its object, and an apprehension arose that some great

catastrophe would befall the earth by an accidental collision with one of these wandering bodies. Whiston had ascribed the Noachian deluge to a condensation of the watery vapours forming a comet's tail, which he supposed to have, when that event occurred, enveloped the earth, and, as there seemed as much reason to believe the matter of the tail to be fire, as water, it was equally feared that a second deluge or a general conflagration might, at a future period, on a like near approach of some comet to the earth, involve the human and animal races, and all the works of men, in one common destruction. It appears that, in 1774, the people of Paris were thrown into the greatest alarm by a memoir of La Lande, in which that astronomer suggests, as a bare possibility, that the perturbating forces of the planets acting on a comet might, in process of time, so change the form and position of its orbit as to bring the nodes into the periphery of the orbit of the earth, and thus expose the latter to the effects above supposed · these apprehensions, however, have been long since shewn to be groundless, for the chances are almost infinite against the occurrence of such a position of the nodes, which the continuation of the perturbating forces would immediately change, and, even if so situated, the chances are equally great against the meeting of the earth and comet, which could only take place precisely at the intersection of their paths; the probability of a direct collision is therefore reduced nearly to nothing. It has been ascertained that no one of the known comets approaches, in any part of its orbit, near enough to the earth, to become capable of producing any sensible effect by its attraction on the waters of the sea; and, that a deluge or conflagration might arise from the envelopment of the earth in the train of a comet is disproved by the fact that this accompaniment is constituted of matter in the highest degree of attenuation.

It will be needless to state the notices concerning the appearances of comets, which occur in the writings of the ancients and bear the impress of their superstitions, let it suffice to observe that Aristotle describes one as being accompanied by a splendid train of light which extended over one-third of the visible heavens and at last ceasing to be visible, in the constella-

tion Orion[a]: and that Justin, speaking of the comet which appeared at the birth of Mithridates[b], says it continued visible during seventy days and was so bright that all the heavens seemed to be on fire, he adds that its train spread over one quarter of the heavens and was four hours in rising and setting. Nicephoras Gregoras, quoted by Halley in his Synopsis Cometicæ, is the first who made any useful observations on these bodies, and he has described the apparent route of a comet which appeared in 1337; but previously to the seventeenth century we have little information concerning them Several are, however, registered in the Chinese annals: Regiomontanus observed one in 1472, which is said to have had an immense train and to have passed through 40 degrees of a great circle in one day; and the movements of those seen by Tycho Brahe and Kepler were carefully particularized.

We have said that the paths of comets were at first thought to be right lines, and when their curvilinear forms were recognized, before a suspicion was entertained that these wandering stars might reappear after intervals of time, it was natural to imagine that the orbits were parabolical, a curve of this kind being the simplest of those which do not return into themselves. Hevelius appears to have been the first who proposed the idea of such an orbit, and he ascribes the motion in that curve to a composition of the impulsive force by which the comet was driven, obliquely as he supposed, from the mass of the sun or of some planet, with a tendency to the sun, produced by the attraction of the latter. The observations of Cassini on a comet which appeared in 1672, and which seemed to describe a route similar to that of one which had been observed by Tycho Brahe, in 1577, first induced an opinion that these celestial bodies sometimes returned to our system, and, consequently, that they describe what are called re-entering curves in their revolutions about the sun.

On the twentieth day of December, in 1680, appeared, above the horizon of London, the finest comet seen since the revival of learning, it became visible in the evening soon after sun-set

[a] Meteor. Lib. I. cap. 6

[b] Historia, Lib. XXXVII. cap 2.

and carried a train of vast extent, but it was then gradually receding from the sun and, after four or five months, it ceased to be perceptible The same comet is, however, said to have been observed at Coburg in Germany in the preceding November, when it was approaching the sun; and, from the data which all the observations furnished, Doerfel computed the elements of its orbit on the supposition that it had the form of a parabola; but Dr. Halley, remarking that a considerable comet had now for the fourth time appeared, at intervals of 575 years; the first at the death of Cæsar, and the third, or that which immediately preceded the present comet, in the year 1106, [according to the Saxon Chronicle,] conceived that they might be the same; and, by trial, he found an ellipse in which, from the theory of gravitation, a comet might revolve in that period and which, at the same time, passed very nearly through the points determined by the observed longitudes and latitudes, and, from the dimensions of this ellipse, it was ascertained that the comet, when in the perihelion point, was at a distance from the surface of the sun less than one-sixth of the semidiameter of this luminary [a].

Dr. Halley also calculated the orbits of two comets which had been observed in 1556 and 1661, and comparing the first with one which, according to Matthew Paris, appeared in 1264, and the other, with one observed by Apian in 1532, he found them, respectively, to be so nearly the same, in the places of their perihelion points and the distances of these from the sun, and also, in the inclinations of their orbits and the places of their nodes, as to afford reason to believe that the two last were identical with the two former, the periodical time of that which appeared in 1264 and 1556 is, therefore, 292 years, and that of the other, 129 years; the former may consequently be expected in 1848, and the other should have reappeared in 1790; as this did not happen, the identity of the comets of 1532 and 1661 is doubtful, or it may be imagined that the perturbations of the other bodies in the system, have so deranged the orbit as to prevent the possibility of its recognition. It is needless to

[a] Principia Lib. III.

say that little reliance can be placed on the computed return of the first comet

In 1682 there appeared a comet in a part of the heavens where one had been observed in 1607, and Dr. Halley, having computed the principal elements of both, found, from their near coincidence, that the comets must be identical: as the interval of these appearances is between 75 and 76 years, he ventured to assign that interval as the periodical time of the comet's revolution and to foretel that it would, next, be visible in the year 1759 The French astronomer, Clairaut, subsequently corrected the value of the period which had been determined by Halley, on account of the perturbations produced by the attractions of Jupiter and Saturn; and, for the first time, a prediction relating to the return of a comet was fulfilled, for this again appeared in 1758 and passed the perihelion point of its orbit in March 1759, only thirty days earlier than the time found by Clairaut; and thus was established the fact that the comets are subject to the same laws of motion as the planets. This is that which is particularly distinguished by the name of Halley's comet; the first notice we have of it is its appearance in 1456, and, from the computations of M. Damoiseau, it may with confidence be expected to pass the perihelion about November 26, 1835 The aphelion point of its orbit was, by Dr Halley, computed to be 1300 millions of leagues from the sun, and the perihelion point, only 20 millions and it is said that, when near this last situation, the comet presented phases, like the moon.

The orbits of above one hundred comets are now considered as known; but, if we except the comet of Halley and two others which were discovered by M.M. Encke and Biela, in Germany, whose computed returns have been satisfactorily verified, the determinations of their major axes and the times of their revolutions, being founded on observations made during the short times in which the bodies are visible, are yet too uncertain to inspire much confidence· the periodical revolution of Encke's comet is accomplished in $3\frac{1}{2}$ years, and that of the comet of Biela in $6\frac{3}{4}$ years, the former came to its perihelion in June, and the latter in November of the last year, 1832. In 1770 appeared a

comet which was said to have been greater than the moon, and, of all that have been observed, this is that which has approached the nearest to the earth: it was visible both before and after its arrival at the perihelion point, and, from its positions in space, MM. Euler and Lexell found its orbit to be elliptical, and the time of its revolution to be between five and six years. yet it has never since appeared, and it is, therefore, evident that its path must have suffered some very great change, probably by the attraction of Jupiter, part of whose orbit appears to be near the aphelion of that of the comet In determining the periodical time of the comet of 1769, the same mathematicians found this element uncertain to the amount of 70 years, for the observations are equally well represented by two ellipses, in which the times of revolution are 449 and 519 years respectively; and Pingré assigns to the period 1231 years. Four periods have been found by M. Bessel for the comet of 1807, of which the least is 1483 years and the greatest 1952 years; and that of the great comet seen in 1811 is said to be either 2301 or 3056 years: it must be concluded, therefore, that much yet remains to be done before the cometary theory will be capable of bearing a comparison with that of the planets

It has, often, been maintained that the regions of space occupied by the bodies of the solar system are filled with an ethereal matter, and that the resistance produced by it is the cause of those inequalities which are observed in the motions of the planets, and which could not, at one time, be accounted for from the theory of gravitation. It is well known, however, that, in proportion as the analytical processes employed in physical astronomy were extended, the several apparent anomalies were found to be comprehended within the grasp of the general theory; and it is, now, no longer necessary to have recourse to the hypothesis of an ether, for the explanation of any phenomenon presented by the sun, moon, or planets. This is not the case with comets, whose irregularities are far greater than those of the other bodies composing the system; and an attempt has been made by M Encke, the astronomer above mentioned, to account for an apparent diminution, in each revolution, of the periodical time and eccentricity of the comet which goes by his

name, by the old hypothesis of an ether diffused through space[*]. As it might be urged that no such ether affects the motions of the planets, the writer of the article, M. Mossotti, observes that, on account of the very eccentric figures of the orbits; the perpetual changes in the forms and velocities, and the smallness of the masses of the comets, the resistance of an ether may become capable of disturbing the movements of those bodies, though its effects are insensible in the movements of the planets But it is evident that the cometary theory must be much further cultivated, and observations greatly multiplied, before it will be possible to decide on the validity of an hypothesis which ought not to be received till every process founded on the theory of gravitation has failed to elicit the object of inquiry

Besides the efforts which have hitherto been made, and those which must, yet, long continue to be made, in order to render perfect our knowledge of the system of planets and comets belonging to the sun, a most extensive field of research, in the regions of the stars called fixed, invites the diligence and promises to reward the labours of future astronomers. In addition to the fixation of the places actually occupied by the stars, and the determination of the changes to which those places appear subject, from the causes above explained, the cultivators of the science have now to attend to the appearances presented by the stars themselves, and to the variations of position which have been observed, and cannot be accounted for by any of those causes, and which, therefore, are considered as resulting from motions peculiar to the stars themselves: observations continued during many years will, it may reasonably be expected, at length afford the means of discovering some general law under which all those variations may be reduced, and of establishing the universality of that law of gravitation which has hitherto been verified only within the limits of the planetary system.

We have had occasion to mention the sudden appearance of some stars and the disappearance of others, and it may now be stated that certain stars seem, alternately, to increase and diminish in brightness, and even to become visible, and invisible, at the ends of certain intervals of time. Hipparchus is the first

[*] Memoirs of the Astronomical Society of London, Vol II. Part I. Art. 5.

astronomer who is known to have witnessed the appearance of what is called a new star; but, from his time, till the latter end of the sixteenth century, very few such phenomena are on record, and of these no particulars are related, if we except that a star as bright as Venus is said to have been seen, in Aquila, in the year 389, of our era. In 1572, Tycho Brahe discovered that remarkable star in Cassiopeia, whose subsequent disappearance excited so much attention among the learned and the ignorant; and, in 1596, Fabricius discovered one in the constellation Cetus which, also after some time, became invisible: this, however, was again observed in 1638, and it was, afterward, found to be one of those which appear and disappear alternately, and to undergo periodical variations of light; but the intervals in which the changes seem to take place are variable, and Hevelius observes that, in his time, it had been for four years invisible. Bulhaldus and Descartes account for these phenomena, and their explanation appears sufficiently probable, by supposing that the fixed stars, like our sun, may revolve on their axes and have on some parts of their surfaces many dark spots; these, being occasionally turned towards the earth by the revolution, cause the stars on which they are, to be apparently less bright, or to disappear entirely, from the deficiency of light; and when the side which has few or no spots comes, afterward, to the same position, the star is again rendered visible.

We have said that the efforts to determine the parallaxes of the fixed stars have not been successful, though, for this purpose, the whole diameter of the earth's orbit has been taken as a base, from the extremities of which the apparent places of the brightest and therefore, probably, the nearest stars, have been observed: the results of the most careful observations having shewn that if such parallax exists it must be less than the errors to which the instruments are subject, and inseparable from them. It ought, however, to be observed, that two celebrated mathematicians, M. Bessel and the Bishop of Cloyne, have confidently asserted, from their own observations, the reality of an annual parallax; but it is remarkable that the observations made by Mr. Pond, the Astronomer Royal, with the accurate instruments belonging to the Greenwich Observatory, seem to prove the con-

trary: we can therefore, at present, only conclude that the distance of the nearest fixed stars from our system is immeasurably great.

These stars are of all varieties of colours, and the telescope shews that an immense number of those which appear single to the naked eye, are really double or multiple, consisting of two or more, seemingly close together and, generally, of unequal magnitudes, but the most remarkable circumstance connected with the phenomena of double stars is that one of them appears to have a movement about the other as a planet moves about the sun. We have, thus, a glimpse of various systems of bodies subject to the principle of gravitation but very differently from that to which we belong: instead of a number of planets and comets revolving about one sun, we perceive suns revolving about suns each, perhaps, attended by his proper system of planets; or it may be that, in some cases, within the orbits of all the planets composing a system are included two or more suns; and any of these arrangements will evidently give rise to a theory of movement far more complex than that which is required to explain the phenomena of the bodies composing our solar system. The astronomical world is indebted to Sir James South for a series of accurate observations, lately made, to determine the periodical times in which the revolutions of many of these double and multiple stars are performed.

Besides the objects which present themselves to the eye of the observer as luminous points, innumerable small cloudy spots are, by the aid of the telescope, seen in the heavens; and Sir William Herschell, who particularly directed his attention to these nebulosities, has determined the position of above two thousand of them, which he has divided into various classes according to their particular appearances. In almost every instance he has found them to consist of very small stars collected in masses which assume a spherical figure, and appear most condensed towards the centre; and, from these circumstances, he concludes that they have been formed by the action of a central force which has drawn the component stars together in groups at immense distances from each other and from the part of the universe occupied by our planetary system.

Of the nebulous matter which does not appear capable of resolution, by the telescope, into separate stars, it is observed by Sir John Herschell, the learned son of the illustrious astronomer above mentioned, that that opinion concerning its nature and uses, in which it is regarded as a self-luminous or phosphorescent material substance in a highly dilated or gaseous state, but gradually subsiding by the mutual gravitation of its molecules into stars and sidereal systems must, in the present state of our knowledge, be looked upon as the most probable[a]. And this opinion seems to be strengthened by the observation of Mr. Pond, the present Astronomer Royal, that the nebula of Orïon is gradually contracting its dimensions, and leaving intervals greater than those formerly observed, between itself and the neighbouring stars[b]. The band surrounding the heavens, and which we designate the Milky Way, is also considered by Sir W. Herschell as a nebulous cluster of stars; within it he places our sun with its attendant planets, and he ascribes its particular appearance to the position we occupy, which he supposes to be near its centre, and to the smallness of its breadth compared with its extent in the direction of the plane of the visible circle. If, as there is abundant reason to believe, this opinion be well founded, it is evident that the magnitude of our vast and splendid system must bear an insignificant proportion to that of the whole cluster; and infinitely less to the extent of the universe, since a spectator placed in any one of the myriads of stars composing the cluster, and looking towards this part of space, would entirely lose sight of this massive earth; even the orbit of the Georgium Sidus would scarcely subtend a sensible angle, and our brilliant sun would be reduced to a point of light only distinguishable by the most powerful telescopes.

Concerning the disposition of the fixed stars there was proposed by Kepler, and described by Dr. Halley in the Philosophical Transactions for 1720, an ingenious hypothesis founded on the idea that these stars are suns, or the centres of systems, held in equilibrio by their mutual attractions, and that the stars of the first magnitude are those nearest to the earth. Now the

[a] Mem. of the Astron. Soc. Vol. II. Part 2. Art 29

[b] Ibid. Vol III. Part 1 Art. 9.

number of points which can be placed on one spherical surface, at a distance from each other equal to the radius of the sphere, is thirteen; it follows, therefore, that if the stars of the first magnitude are so placed, our sun being at the centre of the spherical surface, the equilibrium will subsist and, in this case, there should appear only thirteen such stars Then supposing the stars of the second magnitude to be on the surface of a sphere having twice the radius of the first sphere, such surface would contain fifty-two points at distances from each other equal to the distance of the surface of this sphere from that of the first, and hence it is concluded that there should appear but 52 stars of the second magnitude, for a like reason there should be but 117, of the third, and so on, to those of the least visible magnitude: and though it is not probable that the stars are disposed exactly on the surfaces of such spheres, yet there is nothing to disprove the opinion that the stars which appear to us of different magnitudes are situated nearly at the distances from us which the hypothesis assigns. The stars of the first two magnitudes are, very nearly, equal in number to those supposed by Dr. Halley, but we are scarcely able to form a correct opinion of the number which should be classed under the respective magnitudes beyond the first and second.

The proper motions first suspected by Dr. Halley from a comparison of the latitudes of certain stars, observed by himself, with the latitudes determined by Ptolemy and Tycho Brahe, have been already verified in many of the principal stars, and we have mentioned the assertion of Sir William Herschell that some of these motions seemed to indicate a movement of the whole solar system in space: but, whether this movement is progressive or performed in a circular manner about some unknown centre of attraction, the observations are not yet sufficiently sure to allow an opinion to be formed; and it must also be remarked that many of the observed changes of place in the stars are quite inconsistent with either hypothesis: the complete determination of this question must, therefore, be left to the astronomers of a future age

The ancient catalogues of stars being extremely deficient in accuracy, Flamstead, between 1668 and 1718, by means of the

transit instrument and mural circle with which the Greenwich observatory was then furnished, fixed the position of three thousand stars with respect to their right ascensions and declinations: within that interval of time Dr. Halley made a voyage to St. Helena, partly for the purpose of obtaining the places of the stars in the southern region of the heavens; and, though the atmosphere about the island was unfavourable for astronomical observations, he succeeded in determining the positions of more than 350 stars, but the honour of making a complete catalogue of the southern stars was reserved for La Caille, who accomplished this great task from observations made in the years 1751 and 1752, during his stay at the Cape of Good Hope. Subsequently, an extensive catalogue, containing the places of fifty thousand stars, in both hemispheres, which it cost the labour of ten years to complete, was made by M.M. Le Français and Jerome Lalande; and we now possess in the Berlin catalogue of M. Bode, which contains 17,240 stars with their right ascensions and declinations, computed for the first day of January, 1801, and the annual variations of those elements.

CHAPTER XXIV.

THE TRANSCENDENTAL ANALYSIS EMPLOYED IN PHYSICAL ASTRONOMY.

At what time the planetary theory was first investigated analytically.—Cause of the revolution of a smaller body about a greater.—The problem of *Three Bodies* applied by Clairaut and others to the investigation of the lunar inequalities.—The cause of the moon's acceleration explained by La Place.—The inequalities of the mean motions of Jupiter and Saturn were investigated by Euler and others —The figure of the earth and the constancy of its time of rotation determined by La Place —The variations of the precession, the obliquity of the ecliptic, and the length of the year, shewn.—The figure of the moon determined by La Grange.—The permanency of the planetary system.

THE geometrical analysis which Newton, following the example of the ancient mathematicians, had adopted in his investigations being almost immediately after his death abandoned, the fluxionary, or differential calculus, which had been discovered by that great philosopher and, perhaps independently of him, by the celebrated Leibnitz, was zealously cultivated both in this country and on the continent; and, having been brought to a highly-improved state, it was applied to the solution of problems relating to the phenomena of the heavens. More than half a century, however, had elapsed since the publication of the Principia without any attempt being made to repeat or extend the researches commenced by its illustrious author; but, about the middle of the eighteenth century, a number of learned men, as if by a common impulse, embracing the law of gravitation proposed by Newton, applied themselves to the task of forming on it, as a basis, by the new analysis alone, a complete theory of the planetary movements. among these were Clairaut, Euler, and D'Alembert, who, in 1747, apparently without any knowledge of each other's intentions, investigated the curve which would be described by a body when urged by an impulsive force in a given direction, attracted by a second

body with a force varying, inversely, as the square of the distance, and having its path disturbed by the attraction of a third body acting on both at a finite distance from either.

In the Newtonian hypothesis, all the bodies of the solar system are supposed to attract each other, mutually, according to the same law, and the first step in the enquiry concerning the consequences of the principle, appears to have been that of determining for what reason any one or more should revolve about another, and why this last should not revolve about either of the others; why, for example, the moon should revolve about the earth rather than the earth about the moon, or why both of these should revolve about the sun rather than the sun about them; and in answer to this question, it was rightly alleged that, since the attractive principle resides in every particle of matter, the greater bodies must necessarily exert the greater influence, and cause a greater movement than can be communicated by those which are smaller. When, however, two bodies of unequal magnitude, as the earth and moon, attract each other, the common centre of gravity of both is at a distance from either, inversely proportional to the magnitudes, and the attraction of each causes the other to revolve about this centre of gravity, so that the moon, which is the smaller body, being at the greatest distance from the centre of motion, describes an orbit which necessarily includes that described by the earth about the same point. The sun, also, being vastly greater than all the circumvolving planets is, for a like reason, able to make but a very small movement about the common centre of the system, when compared with that motion which is performed by any one of the planets.

The investigations of Newton had clearly shewn it to be a necessary result of his law of gravitation, that the orbit of any body revolving about a centre of attraction should be a mathematical ellipse, the attraction of the other bodies of the system being excluded. now, delicate observations had shewn that this is neither the figure of the lunar orbit nor of the orbit described by any planet, or by the common centre of gravity of a planet and his satellites; but it was reasonable to suppose that, if the planetary bodies reciprocally gravitate towards each other by

the same law of attraction, such law would suffice to explain the deviations of the orbits from the elliptical figure; consequently, it would be possible, in given circumstances, to compute, from it, the amount of the deviation and of the inequalities produced in the motion of a planet, and this is what has been, at length, satisfactorily proved by the mathematicians of the last and present ages. If, however, the investigation of the figure of an undisturbed orbit; or, in other words, if a theory of two bodies, was thought to be difficult, much more so must have appeared that which relates to the attractions of three, or a greater number of bodies. In fact, the problem of *Three Bodies*, as it was called, presents, if considered in all its generality, difficulties which all the powers of the modern analysis are not able to overcome; but these have been considerably diminished by supposing one of the attracting bodies to be very superior in mass to either of the others, as is the case with the sun and planets; or very remote, compared with the distance between the others, as is the case with the sun when disturbing the moon.

The variations, caused by the attraction of the sun, in the movements of the moon and in the figure of her orbit, are far greater than those in the movement and orbit of the earth or of any one planet by the attractions of the others, and, on that account, the correct determination of them from the assumed law of gravitation is, evidently, the best test of the truth of the law; accordingly, the theory of the moon was almost the first object to which the continental mathematicians applied the powers of the differential analysis. Agreeably to the method of Newton, which has been already explained, and indeed it was not possible that any other should be pursued, the disturbing force, both in the lunar and planetary theories, was conceived to be decomposed into two forces, one acting in the direction of a tangent to the path or orbit of a disturbed body, and the other in the direction of its radius vector: but, from this point, the courses of the investigations conducted by Newton, and by the foreign disciples of his school, diverged from each other, to meet only at the conclusion of the enquiry.

In 1747, both Clairaut and D'Alembert, when treating in a

general way the movement of a body attracted by two others, determined, on the same principles, those different inequalities of the moon's motion in longitude which had, previously, been distinctly ascertained from observation and explained, though briefly, by Newton, in the *Principia;* and their researches were next directed to the determination of the progressive movement which was known to take place in the lunar apogeum. The cause of this phenomenon had, indeed, been contemplated by Newton, but he had rather shewn that the movement was explicable by some particular law of gravitation than by that which is assumed as the basis of the elliptical theory; it was of importance, therefore, that, assuming the Newtonian law to be that of nature, the value of the progression should be determined theoretically, in order that, by its agreement with the results of observation, should such agreement be found to exist, the truth of that law might be established. The process employed by the above mentioned mathematicians is one consisting of approximations successively made; and it happened (which is very remarkable since both arrived, independently of each other, at the same conclusion and at that obtained by Newton himself) that the result was, a value of the progression equal to about half, only, of its observed value: not being aware of the defects in the processes they employed, and not being able to detect any error on revising the steps through which the enquiries proceeded, it was immediately suspected that so great a difference between theory and observation, in a point immediately dependent on the former, could only arise from an erroneous assumption of the law of gravitation, which, it was then supposed, might not be so simple as that proposed by Newton; and Clairaut suggested that it might be inversely proportional, partly to the square and, partly, to the fourth power of the distances of the attracting bodies. This learned analyst, however, in 1749, found, by continuing the approximative process, employing terms which had been before neglected from their supposed insignificance, but which, by integration, acquired small divisors and, consequently, became considerable in value, that the next step produced a correction nearly as great as that which had been previously obtained. The correction thus for-

tunately discovered by Clairaut, and which was immediately adopted by D'Alembert, being applied to the former result, rendered the computed amount of the progression, consequently, very nearly equal to the true value of that element.

We have said that the value of the progression of the lunar apogeum might have been found by supposing the law of the earth's attraction to be different from that assumed by Newton; and, therefore, the determination of that progression by the modification which the sun's perturbating force produces in the general law of gravitation is not to be considered as, alone, proving the truth of this law, though it affords one of the most important arguments in its favour; but, taken in connection with the many other instances in which the results of theory accord with observations, where such accordance would not exist under any other law of attraction, it produces an irresistible conviction that Newton's law is that of nature.

Mayer, in his *Theoria Lunæ*, and Thomas Simpson in his *Tracts*, which were published in 1754, also investigated by the theory of gravitation the elements of the lunar orbit, and succeeded in obtaining correct values of its inclination to the ecliptic, and the motions of the nodes and apogeum: and, besides the equations of the moon's movement in her orbit, which had been before distinguished, they deduced analytical formulæ exhibiting several others arising from the various perturbations to which that luminary is subject; the former astronomer founded also, on those deductions, the correct tables of the lunar motions which we have already had occasion to mention.

Dr. Halley had discovered, by comparing the places of the moon, deduced from the observations of the Chaldeans, of Hipparchus and of Ptolemy, with those obtained from the modern astronomy, that the moon's mean motion was constantly accelerated at the rate of about one degree in two thousand years; and, in his time, it was generally believed that this acceleration, and the corresponding diminution of the moon's mean distance from the earth, would continue till the former body should come in contact with the latter; when, it was conceived, the race of man, and his works, would be destroyed and the earth would revolve about the sun without a satellite. As this diminution

of the moon's motion appeared, at first, incapable of being explained by solar or planetary perturbation, other causes of the phenomenon were to be sought for: M. Bossut suggested that it might be owing to the resistance of a medium diffused through the celestial spaces, and La Place, at one time, imagined that it might be a consequence of the time spent in the transmission of the power of gravity from one body to another: but this great astronomer having proved that these causes are not sufficient to account for the effect; and having discovered that the mean motions of the satellites of Jupiter are subject to secular variations dependent upon the eccentricity of the orbit of that planet, immediately conceived that the variable eccentricity of the earth's orbit might, in like manner be the cause of the apparent acceleration of the moon's motion. The processes he had employed in the theory of Jupiter's satellites were, therefore, applied to that of the moon, and, from the assigned cause, which is itself produced by the combined attractions of the sun and planets on the moon, he discovered that there resulted a secular inequality not only of the moon's motion, but also, of the motion of the nodes and perigeum of her orbit, by which the first is, at present, augmented, and the other two diminished. The values of these inequalities, determined by theory, were found to correspond with those deduced from the observations of the ancient eclipses recorded by Hipparchus and Ptolemy, and La Place remarks that, from them, the ages in which those astronomers lived might be determined within a century or two; from them also, the Hindu Tables, which Bailly supposed to have been formed three thousand years before Christ, might, he observes, be proved to be less ancient than the tables of Ptolemy[a]. The periods in which these inequalities compensate themselves are immense, but the opinion that the moon will at any time come in contact with the earth must now be abandoned, since, by a change in the configurations of the disturbing bodies, effects directly the contrary of those which are now observed will, in time, take place, those effects will continue till a new change again reverses the order of the movements; and there is no reason to believe that this oscillation will ever terminate.

[a] Mécanique Céleste, Tom. V. page 360.

The planets Jupiter and Saturn being much superior in magnitude to any of the others, it is evident that the action of the sun upon them, and their reciprocal actions on the sun and on each other, may be considered as nearly independent of the attractions exercised by the other bodies of the solar system. These three bodies, therefore, constituting, in themselves, almost a complete system, it was natural to apply to them processes similar to those which had for their object the mutual actions of the earth, sun and moon, considering either Jupiter or Saturn as a body revolving about the sun in an elliptical orbit, and disturbed by the attraction of the other planet: the conditions in the two theories seemed, at first sight, nearly the same, and it might have been supposed that the results would be of a like kind. A difference, however, does exist between the theories; for, in that of the moon, the sun's distance is always much greater than that of the earth; whereas the distance between Jupiter and Saturn, when both are in conjunction with the sun, is nearly equal to that of the sun from Jupiter: hence it follows that the perturbations which these planets produce in each other's motions are, in some circumstances, of a nature opposite to those produced by the sun on the motion of the moon about the earth.

We have mentioned that Newton did not investigate the perturbations which the actions of the planets on the sun and on each other produce in the elliptical motions: he observes, however, that the action of Jupiter on Saturn, when both are in conjunction with the sun, is to the action of the sun on Saturn as 1 to 211, and therefore the former ought not to be neglected; but it is a remarkable fact, as is observed by Euler and La Place, that the derangement of Saturn, when the two planets are so situated, is almost insensible, and the corresponding derangement of Jupiter is about six times as great, though the action of Jupiter on Saturn is to the gravity of Jupiter towards the sun in the ratio of 1 to 500 only.

Both ancient and modern observations had indicated great irregularities in the motions of those two planets. Dr Halley, from a comparison of the more ancient observations had perceived a diminution in the mean motion of Saturn, and an acce-

leration in that of Jupiter: M. Lambert had obtained a contrary result from a comparison of the observations of Tycho Brahe with those made in the 18th century, and, lastly, La Lande found that the returns of Saturn to the vernal equinox took place earlier, and those to the autumnal equinox later, than the times assigned by theory, though the positions of Jupiter and Saturn with respect to each other and to their aphelia were nearly the same. From these circumstances it was, generally, concluded that some foreign cause deranged the motions of those planets, or that there was something yet undiscovered in the principle of gravitation itself.

Now Euler, in a paper composed in 1748, for the prize offered by the Academy of Sciences at Paris, investigated the theory of planetary perturbation; and this Essay must be considered as the first of those three which were, nearly at the same time, written by Euler, D'Alembert and Clairaut on the subject; and which are considered as containing the solution of the problem of the three bodies. The essay of Euler is confined, chiefly, to the enquiry concerning the perturbation of the motion of Saturn by the action of Jupiter; but, in it, this great mathematician facilitated, in a most important manner, the analysis of these subjects by developing the perturbating forces and the mutual distances of the perturbating planets, in *sines* and *cosines* of angles augmenting with the *time;* certain errors in his calculations, however, vitiated his results, and, when the longitudes of Saturn computed from the formulæ were compared with the observed longitudes, they were found to differ considerably; the errors not being discovered on a revision of his processes, he was led to suspect that the Newtonian law of gravitation required to be modified: a suspicion which he afterwards shared with the other two mathematicians above mentioned, but which was soon perceived to be unfounded.

It was in considering the inequalities of Saturn dependent upon the eccentricity of Jupiter's orbit, that the integration of his differential equations brought out an inequality of longitude which was expressed by an arc of a circle unaffected by *sine* or *cosine*, and having a coefficient increasing with the *time;* a similar term occurred in the lunar theory; and, since trigonometrical functions

of arcs dependent on the time are essential to the expression of periodical inequalities, it follows that the absence of such functions in a term must indicate the existence of an inequality which, instead of being periodical, would go on for ever increasing: but, by employing particular artifices in the analysis, Euler and D'Alembert were enabled to get rid of the simple arc; and the perpetual inequality of motion, of course, vanished with it.

Euler gave, in 1752, a second memoir concerning the planetary movements, confining his researches, however, as in the former, to the motions of Jupiter and Saturn; and in this he notices his important discovery, that the eccentricities and positions of the aphelia of those planets vary continually, but unequally, in different ages, and that they restore themselves in a period of 30000 years. He wrote a third memoir, in 1756, in which he arrives at the same result as in the first, but by different processes, and assigns the value of two secular equations in the longitudes of Jupiter and Saturn, which, by errors in the calculations, he makes equal to each other, and both additive to the mean longitudes of these planets. In these papers the merit of Euler, in shewing the most direct path by which the results of the theory of gravitation may be obtained, and in overcoming by his profound skill in analysis, difficulties which would have arrested the generality of mathematicians, is eminently conspicuous: he has here exhibited the differential formulæ for the periodical and secular variations of the planetary motions; and though some of these are erroneous, it was comparatively easy for his successors to rectify them by following his steps

To the works of Euler concerning the mutual perturbations of the planets must be added the *Recherches sur le systême du Monde*, published by D'Alembert in 1754, and the Memoirs, by La Grange, in the third volume of the *Mélanges de la Société Royale de Turin*. The former mathematician applied, to the movements of the planets, when disturbed by their mutual attractions, the formulæ by which he had determined the motions of the moon; but, in this enquiry, he does not appear to have added much to the investigations of Euler. La Grange, who seems to have been then unacquainted with the three essays above mentioned, obtained both analytical and numerical ex-

pressions for the secular variations of the eccentricity, the places of the aphelia and nodes, and the inclinations of the orbits of Jupiter and Saturn, which La Place admits to be exact: he found, also, the two secular equations in their longitudes; but, contrary to the determination of Euler, he makes them unequal, and one of them additive to the mean longitude of Jupiter; while the other, which is the greatest, is subtractive from the mean longitude of Saturn: both, however, have been since found to be erroneous.

The enquiries of Euler and La Grange having failed in throwing light upon the cause of the inequalities in the mean motions of those two planets, the subject was taken up by La Place, who was induced to enquire whether those inequalities which, to some persons had appeared to indicate a perpetual acceleration in the motion of one planet and retardation in that of the other, might not be accounted for on the supposition, that the power of gravity was transmitted through space in a definite time; but a contemplation of the effects which, in the lunar theory, might be supposed to have arisen from such transmission of the power of gravity, led to the discovery that the velocity with which gravity must be propagated through space must be fifty million times greater than that of light; and his conclusion is that this cause could not be productive of the inequalities in question. It was reserved, then, for this illustrious disciple of Newton, to deduce from the theory of gravitation the nature and values of those inequalities, to shew, in fact, that they are periodical like the other variations in the elements of the lunar and planetary theories, but that they are compensated at the end of long intervals of time: and he thus explains them in the fifteenth book of the *Mécanique Céleste*.

It is a remarkable result of the reciprocal attractions of the planets that, if we consider only the secular inequalities, the sum of the masses of the planets divided, respectively, by the major axes of their orbits, considered as variable ellipses, is very nearly constant. But, in the expression for the longitude, those inequalities acquire, by integration, the squares of the small coefficients of the time, for divisors; which, therefore, may render them considerable: from thence it follows that the sum of the

products of the secular inequalities resulting from the actions of Jupiter and Saturn, multiplied, respectively, by the masses of those planets, is null: therefore when, in consequence of these inequalities, the motion of Saturn diminishes, by the attraction of Jupiter, that of Jupiter must be accelerated by the attraction of Saturn; and the diminution must be, to the acceleration, in the ratio of the product of the masses of those planets multiplied by the square roots of their major axes, which is nearly conformable to the determinations of Halley On the other hand, when these inequalities accelerate the motion of Saturn, they diminish that of Jupiter in the same proportion, which agrees nearly with the result obtained by Lambert. From these circumstances, and because the mean motions of Jupiter and Saturn are nearly commensurable, La Place was led to infer, in the motion of each planet, the existence of an inequality, which might be compensated only at the end of a long period In fact, as he observes, five times the mean motion of Saturn is nearly equal to twice that of Jupiter, and he concluded, that the terms whose arguments were expressed by the difference of these mean motions might become sensible, by integration, though they should be multiplied by such quantities as the cubes of the eccentricities and of the inclinations of the orbits: retaining, therefore, such terms in the investigation, the result justified his conjecture, and he found that there existed in the motion of Saturn an inequality whose period is 929 years, and in the motion of Jupiter a corresponding inequality which is affected with a contrary sign, and whose period is nearly the same; the difference between the two scarcely amounting to one degree in one thousand years. The nearly commensurable proportion between the mean movements of these planets is, he observes, the cause of several other inequalities; of which the most considerable is one affecting the motion of Saturn, and it is this which, in the last century, rendered the returns of Saturn to the equinoctial points, apparently, irregular; as La Lande had remarked. Thus, adds he, *je vis toutes les observations anciennes et modernes représentées par ma théorie, avec la précision qu'elles comportent. Elles semblaient auparavant, inexplicables par la loi de la pesanteur universelle, elles en sont maintenant une des preuves les plus*

frappantes Tel a été le sort de cette brillante découverte, que chaque difficulté qui s'est élevée, est devenue pour elle, un nouveau sujet de triomphe, ce qui est le plus sûr caractère du vrai système de la nature[a]. La Grange had discovered that the mutual perturbations of Jupiter and Saturn, by making their nodes retrograde on each other's orbits, cause the intersections of both orbits with the ecliptic to advance and retrograde alternately about a mean point on the latter, the inclinations of the orbits to the ecliptic were, also, found to oscillate within certain limits about a mean state, and all these variations appear to require for their accomplishment an interval of many thousand years.

We have seen that Newton and Huygens had determined the figure of the earth, the former, on the supposition that its mass was of uniform density, and the latter, on that in which the different strata varied, in density, from the centre to the surface according to a certain law. But, in 1743, M. Clairaut, in his *Théorie de la Figure de la Terre*, exhibited several general equations concerning the equilibrium of fluids; and, applying them to the earth, supposing it to be a mass consisting of several fluid strata varying in density, and revolving on a common axis, and, again, supposing that the earth consists of a solid nucleus of variable density and covered with a fluid, he proves that, in both hypotheses, an ellipsoid of revolution satisfies the condition of equilibrium in every stratum. he arrives, also, at the remarkable conclusion that, assuming the polar axis and the force of gravity at the equator to be, each, expressed by unity, the excess of the equatorial axis above the polar, added to the excess of gravity at the poles above that at the equator is a constant quantity The theory of Clairaut was rendered more general by D'Alembert in his *Recherches sur le Système du Monde*, and this celebrated mathematician determined the attractions of any spheroid, the equation of whose surface is algebraical; the subject was, however, treated on the like hypotheses concerning the constitution of the earth, with greater precision and elegance by La Place in the third book of the *Mécanique Céleste;*

[a] Méc. Cél. Tom. V. page 324.

and, afterward, in the eleventh book, in order to bring the given conditions nearer to those of nature, he has included the case, in which the fluid leaves uncovered a portion of the solid spheroid from these hypotheses he has investigated the figure which the earth should assume, when in equilibrio between the attractions of its matter and the disturbing forces produced by the actions of the sun, moon and planets, and he finds it to be that of a certain ellipsoid he acknowledges, however, that this may not be the only figure under which an equilibrium may subsist; but he proves that, whatever may be the form of the earth, provided it differs but little from a sphere, the variations of gravity will follow the same law as in a regular ellipsoid.

Experiments made with pendulums, in different parts of the earth, prove that the interior of the latter is not homogeneous; and, a comparison of these experiments with the results of analysis shews, that the densities of the strata diminish from the centre to the surface but La Place observes that the regularity with which the variations in the lengths of the pendulums accord with the law of the variations of the force of gravity (the squares of the sines of the latitudes) warrants the conclusion that the strata are regularly disposed about the earth's centre of gravity; and that their form is nearly that of a spheroid of revolution.

Having shewn the near agreement of the values of the earth's ellipticity, obtained from the measures of the degrees of latitude and from the two inequalities of the moon's motions which he had found to be caused by the oblate form of the earth, with that which results from the theorems directly deduced, on the supposition that the surface of the terrestrial spheroid is a fluid in equilibrio; La Place also infers that the general depth of the ocean must be small, and of the same order as the mean height of the continent and islands above its level, a height which does not exceed one thousand yards.

That great changes have taken place on the surface of the earth is, however, admitted our actual continents have formerly been situated under the ocean, and the latter must, at one time, therefore, have retired from them to the bed which it now occupies, in consequence of partial sinkings and risings of the

ground; but these changes do not appear to have been attended with a depression of the general level of the waters amounting to more than a small part of the difference between the equatorial and polar diameters of the earth; and La Place concludes that there has not, consequently, been any sensible change in the position of the axis of the earth's diurnal rotation, which observations prove, moreover, to have always corresponded with the same points on the terrestrial surface.

In the eleventh book of the *Mécanique céleste* this illustrious mathematician and astronomer also considers the question whether the period in which the earth's diurnal rotation takes place is susceptible of variation: a question of the utmost importance, since the supposition that this element is constant is involved in every conclusion drawn from celestial observations, and since the period of the rotation is always used as an invariable standard for the measure of time. Geological observations, however, present abundant evidence that the earth was, originally, in a state of fluidity, from heat, and a gradual cooling of the mass, by causing a continual contraction of its bulk will, necessarily, produce a corresponding diminution in the period of rotation: for, by the approach of the molecules towards the centre, their radii vectores would, if the movement were not accelerated, describe smaller areas in given times about the axis of rotation; but the momentum of the whole mass being supposed to remain for ever the same, it follows that the equalities of the areas must be preserved and, therefore, each molecule must describe a greater arc in a given time, that is, the velocity of the earth's rotation must increase, and the period of its rotation be shortened, and this effect should continue till the earth has acquired a mean temperature equal to that of the space in which it moves but, from the theory of the secular inequalities of the moon, compared with the observations of ancient eclipses, La Place concludes that the duration of the natural day cannot have varied by so much as one hundredth of a second since the age of Hipparchus. The constancy of the earth's rotation cannot but appear one of the most remarkable phenomena in nature: that, notwithstanding, the variable velocity of the earth in its revolution about the sun, the distortion

of its orbit and the displacement of the plane of the terrestrial equator by the attractions of the celestial bodies, this movement should not have suffered any appreciable change within 2000 years, is a circumstance which we should not have previously imagined, and which must be considered as the strongest example illustrative of the axiom in philosophy, that motion once communicated to a body, if not resisted by an external power, will continue for ever undiminished.

About eighteen months after the publication of Dr. Bradley's account of his discoveries relating to the inequalities of precession and nutation, M. D'Alembert, by analytical processes, succeeded in shewing these inequalities to be the results of the variable actions of the sun and moon on the terrestrial spheroid; and in the *Mémoires de l'Academie des Sciences for* 1754, extending his investigations to the general case, in which the parallels of terrestrial latitude are ellipses, he determines the ratio between the two axes of the ellipse described by the true pole of the earth, and the law of the pole's motion in the periphery of that ellipse La Place has, even, examined the effects produced upon the earth's axis by the movements of the ocean and atmosphere, and he proves that they are the same as if these had formed a solid mass adhering to the terrestrial spheroid. We owe to the same mathematician the investigation of an effect arising from the general attraction of all the planets upon the earth, which consists in a gradual displacement of the plane of its orbit, and in a slow diminution of the obliquity of the ecliptic to the equator, together with a small movement of the equinoctial points, in direct order. The annual amount of the former, in the present age, is about 0″.521, and the latter, about 0″ 313, but theory has, also, proved that the general attraction of all the planets on the earth will not always produce a diminution of the obliquity of the ecliptic, nor a direct movement of the equinoctial points, in process of ages, by changes in the positions of the planets, the effects of their attractions in these respects will become less, they will, afterward, cease entirely, and for a time, the obliquity of the ecliptic and the general retrogradation of the equinoxes will appear constant. but the positions again changing, those secular varia-

tions, as they are called, will again commence, but in contrary orders; then, for ages, the obliquity of the ecliptic will appear to increase and the former direct movement of the equinoxes become retrograde, and these elements will thus appear to oscillate within certain narrow limits which have not yet been accurately defined. The annual amount of the general retrogradation of the equinoctial points is, by theory, found to be equal to 50″.413; and the difference between this quantity and the variation above mentioned is equal to the amount of the retrogradation [50″ 1] determined by comparisons of the modern, with the ancient observations on the longitudes of stars The variability of the movement of the equinoctial points necessarily produces corresponding variations in the length of the tropical year, and since, at present, the general retrogradation suffers, as we have said, a diminution, there ensues, in the length of the year, a corresponding diminution which has been shewn by La Place to be equal to about four seconds, on comparing the present length with that in the time of Hipparchus: the same causes operating, the diminution will continue till it arrives at a certain limit, after which an augmentation will take place to an equal extent, and the value of the year will thus alternately increase and diminish, probably for ever.

In 1764, La Grange investigated the theory of the moon's figure supposing her to have been orginally fluid, he ascertained that, by her movement of rotation, she must, like the earth, have acquired an ellipsoidal form, and he found that, in the direction of the diameter which tends towards the earth, the elevation should be four times as great as that in the direction of a diameter at right angles to the former; this he shews to be the cause of her keeping nearly the same face constantly towards us; and it appears to be a necessary consequence of her figure that the nodes of her equator and her orbit should coincide, but La Grange considers it probable that these are subject to certain small oscillations about their mean point of coincidence

It is, now, to be understood as completely established that the inequalities of motion which were formerly supposed to continue indefinitely, are of the same nature as those which are compensated in comparatively short times, and which are, on that

account, called *periodical,* the former, however, requiring many ages for their compensation, have received the denomination of *secular variations.* During the prevalence of the idea that these inequalities were progressive it was confidently asserted, and Newton himself certainly entertained the opinion, that they would, finally, bring on the destruction of the solar system unless the power of the Creator should interpose to restore the order of things to its original state, but the discoveries of the modern analysis have overturned that notion, and we now consider that a particular intervention of the Deity would be necessary to put an end to that order, which he seems to have constituted for an eternal duration, or even to make any considerable change in the disposition and movement of any one of the planets The most remarkable fact brought to light by analysis is, that the major axes of the orbits, and the times of the revolutions of the planets about the sun, though subject to periodical variations, are entirely free from those called secular: La Grange, in the Mémoires of the Berlin Academy for 1776, has shewn that, in the solar system, neither the reciprocal attractions of the planets nor their oblate figures can, while the perturbating forces are very small compared with the attraction of the sun, produce any but temporary alterations either in the figures of the orbits or in the times of the revolutions, his argument being that the changes of the major axes, on which the other elements depend, can always be expressed by the sines and cosines of angles and are, consequently, periodical; a circumstance which may be considered as demonstrating the permanency of the system to which we belong.

In conclusion, let it be observed that, should any new theory be hereafter proposed to account for the celestial movements, it may, without hesitation, be pronounced useless; since that which rests on the Newtonian principle of gravitation has been found capable of accounting for the most minute variations in the planetary motions, and since, on comparing the results obtained by the formulæ deduced from it with actual observations, the differences are, in all cases, very nearly within the limits of the errors arising from the defects of the instruments, or from the imperfection of human vision. Therefore, though

the principle above mentioned be objected to as hypothetical, no advantage will be gained by introducing any other, which must be no less so, and which cannot possess the merit of superior simplicity It follows that, in astronomy, human ingenuity will, probably, in future, be able to accomplish little more than an improvement in the means of making observations, or in the analysis by which the rules of computation are investigated: it must be owned, however, that the last subject offers an ample field for the exercise of mathematical talent, pure science, in its present state, being still very inadequate to the direct attainment of the ends proposed, while its intricacy, in the higher departments, is such as to render the processes unintelligible to all but the few distinguished persons who, by Nature and profound application to the subject, are qualified for such researches.

THE END.

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